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FINAL REPORT

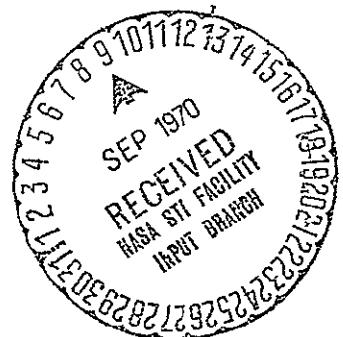
DETERMINATION OF PROCESSING AND TEST FACILITY REQUIREMENTS FOR LARGE SOLID ROCKET MOTORS

VOLUME I: TASK I

FACILITY MODIFICATION FOR FULL-LENGTH 260-IN. -DIA MOTOR PROCESSING AND TEST

by:

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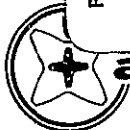


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H. V. Bankaitis, Project Manager

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VOLUME I: TASK I - FACILITY
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Contract NAS3-12041

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ABSTRACT

A detailed processing plan, defining minimum-cost facility modifications and equipment requirements, was developed for the processing and static testing of a full-length 260-in. (6.6m)-dia solid rocket motor at the Aerojet-General Corporation's Dade County, Florida, plant. For in-plant motor case movement, it was determined that a dock on an existing canal and a connecting roadway would be required. Process equipment and a temporary structure at the General Processing Building would be necessary for motor case insulation. Propellant processing would necessitate detail premix dispensing and mixer improvements, and an expansion of oxidizer grinding capability. Propellant casting requirements include an adjustable multiple-tube bayonet casting system and a new environmental shroud. Several structural support modifications in the cast-cure-test caisson would be required. Thrust vector side force measurement systems, increased instrumentation capability, and support system additions also would be required at the test facility.

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I. SUMMARY

This report presents the results of Task I, Facility Modification, of Contract NAS3-12041, Determination of Processing and Test Facilities Requirements for Large Solid Rocket Motors. The objective of Task I was to define, on the basis of minimum cost, the minimum modifications necessary at the Aerojet-General Corporation's Dade County, Florida facilities for the processing and static test firing of a 260-in.(6.6m)-dia solid rocket motor containing 3.4M lb (1.542,000 kg) of propellant and equipped with a nozzle thrust vector control system. A detailed processing plan was developed, placing special attention on the areas of case handling, case insulation, propellant processing and casting, and static testing.

It was determined that the previous approach of overland transportation of the short-length cases from the Bayfront Park dock was probably unfeasible because of the higher overall envelope of the full-length case on a transporter, resulting in relatively uncertain cost factors. A more direct approach of barge transport by way of an existing canal to an on-plant unloading location would require construction of approximately two miles (3.2 km) of road. This would result in a slightly higher overall cost, but would be simpler. The latter approach was selected on the basis of feasibility and greater cost certainty. The existing stiff-leg crane could be utilized for case handling at the cast-cure-test facility with the addition of an off-the-shelf boom extension.

Insulation facility and equipment requirements were developed to incorporate the design and processing plan engendered under the Large Solid Rocket Motor Cost-Optimized Insulation System Development Program, Contract NAS3-11224. Specific equipment items for processing the trowelable insulation were identified. Modifications to the General Processing Building and requirements for a new environmental enclosure building addition were outlined, and include utilization of existing environmental systems and components.

I. Summary (cont)

Modifications to propellant processing facilities include detail changes to improve premix metering, mixer deaeration, and mix station oxidizer dispensing. A major modification was the addition of a second Mikro Atomizer system in the oxidizer grind station in order to provide adequate capacity to support the existing propellant mixing rate capability. An adjustable 12 bayonet casting concept was devised to accommodate the processing guidelines generated under the 260-In.-Dia Motor Propellant Improvement Program, Contract NAS3-12002.

Alteration of the static test facilities to accommodate the increase in size from the short-length motor includes modifications in the caisson to position the forward end of the motor at a lower level. The higher total force is within the existing capability. New equipment would be required for anti-flight retention, posttest quench, and aft-end ignition support.

Requirements for both flexseal movable nozzle and liquid injection thrust vector control systems were investigated. Approximately twice the existing number of instrumentation channels and control circuits would be necessary. In addition to the side force load cells and flexures, a flexure system for isolation of the axial force measurement system would be required for accurate side thrust measurement. Support systems for both types of thrust vector control systems were defined, emphasizing maximum use of existing or available equipment. The total estimated cost of facility and equipment modifications is in the range of 1.105 to 1.336 million dollars, depending on the type of thrust vector control system and ignition system assumed.

II. INTRODUCTION

A. PURPOSE OF REPORT

This report is the first of two volumes of the final report for Contract NAS3-12041, Determination of Processing and Test Facility Requirements for Large Solid Rocket Motors, performed by the Aerojet Solid Propulsion Company for the Lewis Research Center, National Aeronautics and Space Administration. The work reported in this volume encompasses Task I, Facility Modification for Full-Length 260-In.-Dia Motor Processing and Testing.

B. BACKGROUND

The Aerojet-General Corporation's plant in Dade County, Florida, has been utilized successfully in the processing and static test firing of three 260-in.(6.6m)-dia short-length solid rocket motors. While the facilities were adequate for their intended use, the potential requirement for processing and testing larger motor equipped with nozzle thrust vector control systems would necessitate facility modification and expansion. The present facility consists of propellant processing stations with associated support buildings and a Cast-Cure-Test (CCT) caisson. The caisson is capable of containing much larger motors, but modifications would be necessary for support of a longer motor and for measurement of side forces resulting from thrust vectors during static testing. Consideration must be given to propellant production adequacy with respect to reserve capacity in the event of equipment breakdown. In addition, the quantity and rate of production of motors will influence the type and magnitude of facility expansion.

C. PROGRAM OBJECTIVE

The objective of this program was to define the extent and associated cost of the modification of the Dade County Plant (DCP) facilities required to process and static test fire 260-in.(6.6m)-dia solid rocket motors containing

II.C. Program Objective (cont)

at least 3,400,000 lb (1,542,000 kg) of solid propellant and equipped with a nozzle thrust vector control system. Acceptability of the modifications were based on their low cost and final facility adequacy to process the required motors.

D. SCOPE OF WORK

Task I of this program encompassed the development of a detailed processing plan and the definition of facility modifications and equipment requirements for a single full-length 260-in.(6.6m)-dia motor. In developing the processing plan, only the minimum facility modifications was considered. Special attention was placed on case handling, case insulation, propellant processing and casting, and static test operations. Insulation processing requirements were based on the results of Contract NAS3-11224, "Development of Cost Optimized Insulation System for Use in Large Solid Rocket Motors." Propellant processing and casting requirements included the processing guidelines generated under Contract NAS3-12002, "260-In.-Dia Motor Propellant Improvement Program," and emphasized improvements in premix dispensing, oxidizer grind station output, and propellant mixing and casting capabilities.

E. COST ESTIMATES

Cost estimates for facilities shown in this report are in 1970 dollars and are based on the assumption of government expenditure through Aerojet. Actual construction is assumed to be accomplished by outside contractors, so that to the estimated direct costs are added contractors' fee and profit and direct charges for Aerojet engineering and drafting services. Accuracy of the estimates is commensurate with the scope of the study effort and are probably valid at least within ten percent.

III. MOTOR DEFINITION

The 260-in.(6.6m)-dia solid rocket motor selected for reference use in this program is the design presented in Reference (a); the Saturn IB Improvement Study, Phase II, by the Douglas Missile and Space Division. This motor contains 3,400,000 lb (1,542,000 kg) of propellant and is equipped with a liquid-injection thrust vector control system (LITVC) on an 11:1 expansion ratio conic nozzle. Motor design and processing details were provided under subcontract by Aerojet. Later, design studies by Aerojet indicated equivalent performance could be achieved with a contoured 9:1 expansion ratio nozzle, and that movable nozzles, including those with flex-seals, were attractive alternatives, a version of which is shown in Figure 1. In addition, the fore-end ignition system employed in that design was a departure from the aft-end mounted igniter of 260-SL motor experience. Therefore, processing and test requirements of the principal design alternatives were considered in this study.

IV. CASE HANDLING

A. DESCRIPTION OF OPERATIONS

In-plant operations involving motor case handling consist of receiving operations, transport to the general processing building, installation and cribbing for insulation operations, transport to the Cast-Cure-Test (CCT) facility, and installation in the CCT caisson. The handling operations for the full-length case are functionally the same as those performed with the two short-length cases received and processed in 1965. The short-length case handling operations are summarized in the following paragraphs.

Handling rings were installed on the forward and aft skirts during case fabrication. The completed chambers were installed horizontally on a strongback frame equipped with pneumatic-tire dollies, and tandem bars for connecting the dollies. The chamber was supported by the handling rings on

IV.A. Description of Operations (cont)

turning rolls mounted on the strongback. The chamber and transporter were secured on a 40 by 120 ft (12.2 by 36.6m) barge (see Figure 2) and towed to the dock at Bayfront Park, east of Homestead, Florida. The transporter was raised from the cribbing on the barge deck with jacks and the dollies were installed. Off-loading consisted of towing the transporter onto the dock over a wooden ramp. The deck level was maintained by adding ballast.

The overland route to the Dade County Plant was on county and city roads to U.S. Highway One and State Highway 27 through Homestead and Florida City. On-plant movement was from the main gate to the processing building for insulation and lining, and to the CCT caisson for installation for casting. The chamber was lifted from the transporter at the CCT facility using a 300-ton (272,000 kg) stiff-leg derrick with two portable cranes for rotation. Installation in the caisson required only the stiff-leg derrick.

B. RECEIVING

In developing a process plan for a full-length 260-in.(6.6m)-dia motor, receipt of the motor case on-plant will be considered first. Figure 2 gives a comparison of the barge and transporter arrangements for the short-length and full-length motor cases. If it is assumed that the case will be transported from the fabricator's plant by barge, there are two routes to receiving the case at the plant. The first is to repeat the earlier experience and off-load the case and transporter at Bayfront Park, then haul the load on public roads to the main entrance of the plant on State Highway 27, as indicated on the map shown in Figure 3. The second route, also shown in Figure 3, would be to transport the case by barge across Manatee Bay to a point on Central and Southern Florida Flood Control District Canal C-111, where off-loading for movement on on-plant roads could be accomplished. Both routes were investigated and compared on the basis of feasibility and cost.

IV.B. Receiving (cont)

1. Off-Loading at Bayfront Park

A 110 ft (33.5m) long change could navigate the previous route with respect to turning radii.

A new transporter design utilizing 16 eight-wheel dollies would be required for the heavier load.

The vertical height of a 260-FL chamber load would be increased by at least five feet (1.5m). Three feet (0.9m) of this increase is due to the extra set of tandems on a new transporter and two feet (0.6m) due to the larger handling rings.

It is not likely that telephone and electric wires could be raised this additional five feet (1.5m) without disassembly. It is possible that new poles would be required.

A modification to the unloading dock would be required at Bayfront Park due to the longer load. This would require permission of the County Park System.

2. Off-Loading on Canal C-111

A canal extension from Canal C-111 to the intracoastal waterway has been dredged across Manatee Bay. The depth of this canal extension is seven feet (2.14m) with the exception of two points at which the maximum depth is 5.95 feet (1.81m) below mean sea level. These two points could be dredged to seven feet (2.14m) if needed, but for this load, the barge draft probably would not exceed four feet (1.22m).

An unloading dock would be required on-plant.

IV.B. Receiving (cont)

The chamber could be shipped on a simplified transporter and dolly arrangement if off-loaded on-plant.

Some on-plant road development would be required for movement from the canal extension to the G.P. Building.

From these results, it would appear that the second approach is more desirable, since unloading docks would be required for either route and the second approach has fewer unknowns.

Cost data for the public highway route is not available in adequate detail for accurate estimates, and additionally, it is difficult to assess the complications of the increased load envelope, particularly in relation to interference with utility lines. The short-length cases were delivered under package contracts which included the barge, transporter, and all move costs. Estimates have been made for the transporter cost, but the writeoff for the strongback, which was fabricated specifically for this use, is not known. However, since the contract values for the first and second chambers were similar, \$116,000 and \$109,000, respectively, it may be assumed that the writeoff was split equally. By subtracting the estimated barge rental and towing cost of \$14,000 from the average 260-SL chamber move cost of \$112,500, the resultant \$98,500 can be assumed to include all other costs including a writeoff for the transporter, which is estimated to be \$28,500. If the net move cost of \$70,000 is updated to 1970 costs at a rate of 4% per year compounded, the net move costs for a 260-SL chamber would be \$85,200 in 1970. One of the principal increases in cost due to the five-foot height increase for the full-length case envelope would be for raising or moving utility lines. The cost of raising wires for each 260-SL case was approximately \$9,000. A cost of \$25,000 is assigned to this element, resulting in a summary cost, excluding transporter, barge, and temporary dock, of \$110,200.

IV.B. Receiving (cont)

For comparative purposes, the cost of the second approach is related principally to the construction of a road linking the canal to the existing on-plant road system, since the costs of a temporary unloading dock and a transporter would be roughly comparable to those for the first approach. The route initially envisioned was to follow an existing graded road north past the burn area, and then utilize the paved roads to the General Processing Building. However, existing easement agreements apparently would restrict development of that roadbed. Therefore, the shortest route for a new road would be directly to the CCT area, a distance of slightly over two miles (3.2 km), allowing use of the main road to the G.P. Building.

The cost of this road would depend on the type of surface required, but it is assumed that, since the projected use in this task of the study is for one-time use, a compacted graded surface of Miami oolite fill would be adequate. A 40-ft (12.2m) wide road with sloping shoulders, constructed by the removal of four feet (1.2m) of mucky marl and the addition of five feet (1.5m) of compacted fill, is estimated to cost \$116,800. The cost of unloading and movement to the G.P. Building is estimated to be \$10,000. While the total of \$126,800 is slightly greater than the cost of the first approach, less stringent requirements for an on-plant transporter would reduce the cost by about \$16,000, resulting in a net total of \$110,800. Because of the comparable costs and because of the greater unknowns in the first approach, the concept of an on-plant dock was selected.

The receiving dock at Canal C-111 required for this task would consist principally of a concrete retaining wall, and a graded and paved unloading area. The canal is 100 feet (30.5m) wide at the 12 foot (3.7m) depth with 2:1 graded sides. Since the 40 by 120 ft (12 by 37m) barge used for the short-length chambers is apparently adequate for the full-length chamber, the barge could be turned to any desired angle for off-loading. In Figure 2, the barge is shown positioned across the canal. Therefore, no additional dredging is required. The estimated cost of the dock is \$15,800.

IV. Case Handling (cont)

C. ON-PLANT MOVEMENT

Movement of the motor case on plant roads would require no additional facilities or equipment. Installation of the case at the G.P. Building for insulation operations would be accomplished in a similar manner to the short-length cases. The transporter would be backed into the environmental enclosure and cribbed in place. Removal of the dollies would not be necessary, since the anticipated time required for case priming and insulation would be much shorter than required for the short-length motors.

D. INSTALLATION IN CCT CAISSON

Installation of the insulated case in the CCT caisson would be conducted using the 300-ton (272,000 kg) stiff-leg derrick with portable cranes required for rotation. The boom height of the stiff-leg derrick would have to be extended at least 50 ft (15.2m), as shown in Figure 4. The estimated weight of the insulated case, including handling rings and casting adapter, is 185 tons (168,000 kg). The existing derrick has a rated load capacity of 300 tons (272,000 kg), excluding the hook, at radii up to 60 ft (18.3m). The actual hook capacity is 250 tons (228,000 kg) at 70 ft (21.4m) radius, which is the caisson center distance. With the extended boom, the available capacity would be 225 tons (204,000 kg) at that distance.

At the time of the acquisition of the derrick, an additional 70 ft (21m) was available with the off-the-shelf hardware for approximately \$10,000. The existing cable length is adequate to accommodate this extension. The total cost of purchase and installation is estimated to be \$20,000.

V. CASE INSULATIONA. REQUIREMENTS

The final report for the Large Motor Insulation System Development Program, Contract NAS3-11224,* was reviewed and requirements for this study were incorporated as summarized below.

1. Design Description

The selected 260-FL motor insulation system design utilizes trowelable polybutadiene materials. Design characteristics are summarized in the following table:

<u>Motor Location</u>	<u>Material</u>	<u>Weight, lb (kg)</u>
Forward Dome	IBT-100	7,410 (3,361)
Sidewall	IBT-106	16,630 (7,543)
Aft Dome	IBT-100	11,005 (4,992)
Propellant Boots	IBT-106	4,535 (2,057)
Nozzle	IBT-100	5,065 (2,297)

2. Process Sequence

The general sequence of operations envisioned for installation of the IBT-100/IBT-106 insulation system into a 260-in.(6-6m)-dia full-length motor is as follows:

Move motor case into insulation processing facility and mount on motor-driven turning rolls.

* NASA-LeRC Report NASA CR-72584, "Development of Cost-Optimized Insulation System for Use in Large Solid Rocket Motors," Vol. IV: "Task IV - 260-In.-Dia Motor Insulation System Design and Process Plan," dated August 1969.

V.A. Requirements (cont)

Install lighting and equipment truss.

Install environmental control equipment.

Vacuum gritblast, clean, and prime case interior with epoxy primer.

Process and install forward and aft dome insulation.

Cure dome insulation at ambient for 24 hr, then at 135°F (57°C) for 48 hr.

Install sidewall insulation.

Cure sidewall insulation at ambient for 24 hr.

During 24 hr ambient cure, install aft casting adapter.

Cure sidewall insulation at 135°F (57°C) 48 hr.

Apply silicone release agent to forward and aft dome insulation surface.

Install forward and aft propellant boots.

Cure propellant boots at ambient for 24 hr, then at 135°F (57°C) for 48 hr.

Install precured aft boot extension.

Inspect with nondestructive test (NDT) methods.

V.A. Requirements (cont)

Repair as required.

Remove environmental control equipment and lighting and equipment truss.

Install environmental covers. .

Move case to CCT facility for propellant loading.

The foregoing operations will require approximately 20 working days, assuming three-shift operation. A process flow sheet is shown in Figure 5. The environmental control system must be capable of providing an interior temperature of $135 \pm 5^{\circ}\text{F}$ ($57 \pm 3^{\circ}\text{C}$), and a relative humidity level of 30%, maximum. The motor-driven turning rolls must be capable of a minimum constant chamber speed of 2 revolutions per hr.

3. Materials

Based on a 15% loss factor and a maximum batch size of 3,000 lb (1361 kg), the following table summarizes the number of insulation material batches required for insulating a 260-FL motor:

<u>Location</u>	<u>No. of Batches</u>	<u>Batch Size, lb (kg)</u>	<u>Total Weight of Insulation Mixed, lb (kg)</u>
Forward Dome	3	2841 (1288)	8,522 (3865)
Sidewall	7	2732 (1239)	19,124 (8674)
Aft Dome	5	2531 (1148)	12,656 (5740)
Propellant Boots	2	2608 (1183)	5,216 (2365)
Nozzle	2	2913 (1321)	5,826 (2642)

V.A. Requirements (cont)

4. Equipment

The following equipment will be required, at an estimated cost of \$75,900.

Lighting/environmental equipment truss
Truss support
Forward dome sweep template
Aft dome sweep template
Aft dome sweep template support
Weighted mobile trowel
Egress ramp
Lightweight insulation pot
Insulation pot stand

B. FACILITY MODIFICATIONS

1. Concrete Surface Extension

The area required to maneuver the 120-ft (36.6m)-long by 37-ft (11.3m)-high chamber/transporter into the G.P. building add-on will be significantly greater than that required for the 260-SL motors. As shown in Figure 6, the area would be extended by approximately 36 to 148 ft (11.0 to 45.2m), at an estimated cost of \$5,600.

2. Temporary Air-Lock Add-On

The existing temporary building is both dimensionally and structurally inadequate for further use. Consideration was given to the necessity of this structure. For the single-motor program, elimination of the external protective structure could save a sizable expenditure. However, the

V.B. Facility Modifications (cont)

reasons for providing external protection for the 260-SL motors apply equally well to the 260-FL motor. First, the temporary structure provides essential protection to the external motor case, turning rolls, and transporter from the corrosive effects of Florida weather, such as high humidity, heavy rain, and hurricane-force winds. Second, the temporary building provides an air-shroud around the case which reduces the heat-loss from the case during curing/heating cycles. This in turn reduces the capacity required from the air-lock environmental control system by more than one-half. In fact, external heating of the case may be necessary for adequate cure of the insulation. The structure would be similar to that used for the 260-SL motors, shown in Figure 7, except that the overall length will be 114 ft (34.8m) and the minimum overhead clearance height will be 37 ft-3 in. (11.4m), as shown in Figure 8. The estimated cost of this structure is \$82,500.

3. Air-Lock Hoisting Capability

The G.P. building air-lock is equipped with ceiling-high mono-rails and 2-ton (1,810 kg) air or electric hoists. The 260-FL motor lighting/equipment truss and loaded insulation pots would exceed structural capability of the existing monorails and hoists. The existing 12 WF 27 crossbeam and monorail shown in Figures 8 and 9 would be replaced with a larger beam and support structure which are capable of carrying the higher loads anticipated during 260-FL motor processing, e.g., truss, loaded insulation pots, tooling.

4. Air-Lock to Motor Opening

The 260-FL chamber centerline when delivered to the G.P. building for processing would be 4-ft (1.2m) higher than that of the 260-SL motors. This increase is due to an extra set of transporter tandems and larger handling rings. As a result, the air-lock to motor opening must be raised 4-ft (1.2m) to accommodate the 260-FL case. This modification is shown in

V.B. Facility Modifications (cont)

Figure 9. The height of the platform also must be raised, as shown in Figure 8. The cost of this modification and the monorails and hoists is estimated to be \$27,500.

5. Air-Lock Access Doors

The roll-up door on the north wall of the air-lock, between the air-lock and main G.P. building, is not high enough for installation of the lighting/equipment truss. Also, a larger door is required to accommodate movement of the insulation process tooling. Modifications would consist of removal of the existing roll-up door, reworking the existing door jamb, and installing a 28-ft high swing open hinged door as shown in Figure 8. The estimated cost of the door installation is \$8,000.

6. Environmental Control System

The 140°F (60°C) maximum temperature required for the insulation cure cycle is some 40°F (22°C) less than the air temperature used to dry the 260-SL-3 insulation. Based on a cursory heat transfer analysis, the present environmental control system capacity might be adequate for 260-FL motor processing operations under most weather conditions, provided an external temporary structure is installed. However, the temperature drop through the thick sections of insulation could result in an inadequate state of cure or a protracted cure cycle. To assure system adequacy for the required cure cycle under all weather conditions, the most expedient approach is to provide external heating to the case. The portable heating and air distribution system, shown installed in Figure 10, utilizes the portable 40 Boiler HP (392,000W) steam boiler system at the CCT, which would be more than adequate for this requirement. The installed cost of this system would be approximately \$16,000.

VI. PROPELLANT PROCESSING AND CASTING

A. DEFINE RESULTS OF CONTRACT NAS3-12002

1. Mix Cycle

Based on results from the 260-in.-dia Motor Propellant Improvement Program (Contract NAS3-12002), the following changes or additions will be made to the vertical batch mix cycle.

a. The minimum mixer vacuum during the vacuum mix cycles will be 28-in. (710 mm) Hg, measured in the mixer, as opposed to the previous 27 in. (690 mm) Hg measured in the vacuum line.

b. The mix cycle will include a 10-min. interim vacuum mix after oxidizer addition and before final fuel addition.

c. The final vacuum mix cycle will be 30 min minimum.

2. Formulation Implications

The differences between the improved formulation ANB-3350, developed on Contract NAS3-12002, and the formulations used to cast 260-SL-1, -2, and -3 will not, per se, necessitate any change or additions to production facilities. A greater total weight of burning rate additive will have to be handled during premix make-up, and the newer more stable curing catalyst can be added directly to the premix, but none of these factors are expected to require facilities changes for production of a single full-length motor. Based on tentative requirements established on Contract NAS3-12002 for propellant flow behavior, it will be necessary to provide a means for determining flow properties, i.e., a Rotovisco viscometer and a refined "falling ball" device.

VI.A. Define Results of Contract NAS3-12002 (cont)

3. Casting Limitations

Based on the results of Contract NAS3-12002, the bayonet submergence should be limited to 18-in. (46 cm) to preclude movement of high viscosity propellant. In order to avoid excessive delays caused by frequent pigging, cutting, and reinserting of the bayonets, it will be necessary to provide methods for adjusting the depth of submergence without removing the bayonet from the motor.

Observations during the casting of the subscale and full-scale molds on Contract NAS3-12002 strongly indicate that a potential defect-formation problem could exist if the twelve-fin forward section of a full-length motor were cast with the current three-bayonet casting facility. This would require the propellant to flow over long path lengths and around corners of the core to fill the fin area. The long flow path length combined with the abrupt changes in flow direction are conducive to defect formation of the type observed during casting of 260-SL-3. For this reason, designs to permit casting with twelve bayonets simultaneously between each of the twelve fins must be considered.

B. FUEL PREPARATION

1. Description

The Fuel Preparation Building contains the necessary equipment for the preparation and metering of liquid and slurry fuel ingredients for propellant mixing. Premix is prepared, containing polymer, plasticizer, aluminum powder, and other liquid and solid components, and is dispensed into a transporter for transfer to the continuous mixer storage tank, or is metered directly into the mobile mix bowls for the batch mixers. Final fuel, consisting

VI.B. Fuel Preparation (cont)

of curing agent and cure catalyst (depending on the formulation), and either is dispensed to a transporter for transfer to the continuous mix storage tank, or is metered into plastic carboys for use in the batch mixers.

2. Capability of Current Facility

The production capability of the current facility is dependent on the storage capacity for the finished premix since storage capacity governs the make-up tank availability. The storage capacity and hence the production capability is greatest when the vertical batch and the continuous mixers are all being operated, such as for 260-SL-1 and SL-2. In this operation mode, premix can be stored in the CM supply tank, the transporter and the metering tank. When only the vertical batch mixers are being operated, premix may be stored only in the metering tank and the premix production rate is governed by the rate of usage in the mixers.

The current premix storage capacity for the different mixer operation modes is illustrated with the diagram shown in Figure 11.

As illustrated by the actual data for processing of the 260-SL-1, -2 and -3 motors (Figure 12), the premix production capacity of either operation mode does not limit the propellant production.

3. Deficiencies in Current Facility

a. Premix Metering

The premix is dispensed into the vertical mix bowls by means of a positive displacement metering pump. The amount dispensed into the bowl is determined by a mechanical counter which counts the number of pump

VI.B. Fuel Preparation (cont)

impeller revolutions. When the required number of revolutions has occurred, valves which divert the premix stream to recirculation are automatically actuated. The pump revolutions are now monitored by a second mechanical counter. Previously, an electronic counter was used for primary control and a mechanical counter for confirmation, but when the electronic counter proved to be unreliable, the two mechanical counter arrangement was adopted.

Precise control of the quantity of premix displaced into the mix bowl is necessary to the control of propellant properties. While there has been no history of propellant compositional deficiencies attributable to premix dispensing errors, only an indirect measurement of the quantity of premix delivered and is accurate if the pump is functioning properly. A secondary monitoring system independent of the pump would provide a direct measurement confirming that the correct weight of premix was delivered.

Two different types of monitoring systems were considered, i.e., a recording flow meter on the discharge side of the pump and a weigh tank. The simpler and preferable method is the installation of a flowmeter at the discharge of the metering pump. An amplifier attached to the flowmeter sensor would transmit a signal to an integrating device with a digital readout. Starting, stopping and resetting of the readout would be coordinated with the existing metering system.

The other method requires the installation of a separate tank, complete with a weighing system, water jacket, and other necessary appurtenances. Premix would be pumped into the tank, then metered by loss-in-weight as it is discharged by pressurization of the chamber. As well as being more expensive, this method adds more equipment to an already crowded area.

Cost estimates of \$10,955 and \$26,980 were obtained for the recording flowmeter and weight tank systems, respectively. Since the

VI.B. Fuel Preparation (cont)

probable performance of either system is comparable, the lower cost flowmeter system is selected.

b. Aluminum Powder Addition

The premix processing step which primarily determines the length of the batch preparation cycle is the addition of the aluminum powder to the make-up tank. Approximately 10 drums of aluminum are required for each batch of premix and the method of addition involves installing a special funnel and valve on the drum, inverting it with a hoist, and feeding the powder to the tank through a Syntron feeder. Although this method is relatively slow, the premix make-up capability was sufficient to keep up with even the highest propellant production rates.

There were occasional malfunctions (spring breakage) of the Syntron feeder which interrupted premix make-up, especially during the processing of motor 260-SL-2. As part of any reactivation of the premix facility, the Syntron feeders would need to be thoroughly overhauled, new, stronger springs installed, and the operating conditions of vibration frequency and amplitude optimized.

c. Tempered Water System

The existing tempered water system has been deficient on some occasions when transfer activity is high, apparently due to inadequate chiller capacity. In addition, the level controls on the water tanks have malfunctioned occasionally. These deficiencies would be corrected by the installation of a parallel heat exchanger and rework of the level controls, at an estimated cost of \$5,500.

VI. Propellant Processing and Casting (cont)

C. OXIDIZER PREPARATION

1. Description of Process

The propellant formulations for 260-in. (6.6m)-dia motors require the use of blended slow speed Mikropulverizer (SSMP) and Microatomizer (MA) ground oxidizer. A schematic diagram of the oxidizer process operations is shown in Figure 13. Unground oxidizer is discharged from Tote bins into the SSMP and MA mills. The ground product is fluidized into a product weigh bin and then the weight of each grind required for the desired oxidizer blend ratio is discharged into a ribbon blender. The blended oxidizer is then dispensed into a Tote bin for transfer to the propellant mixers.

2. Capabilities of Current Facility

The production capability of the current facility for the SSMP/MA oxidizer blends used in 260-in. (6.6m)-dia motor propellants is theoretically dependent on the rate at which the MA fraction of the blend can be ground, i.e., the MA grinding rate is limiting. A plot of the oxidizer blend production rates vs SSMP/MA blend ratio presented in Figure 14 shows that at 100% grinder utilization, 2,400-lb/hr (1,090 Kg/hr) of MA, 8,000-lb/hr (3,620 Kg/hr) of a 70/30 SSMP/MA blend could be prepared. This 100% utilization however must be adjusted to allow for normal maintenance, lost operating time (lunch and shift breaks) and planned down-times for cleaning of valves and pants legs and bin shake-downs. Fluidization of the MA oxidizer from the grinder into the weight bin and blender has been found to be the limiting factor rather than grind rate. However, actual performance is a better measure of what can be expected in the processing of propellant for a full-length motor. The peak production rate achieved for a 24-hr period during the processing of 260-SL-2 (70/30 SSMP/MA) was 5,104 lb/hr (2,310 Kg/hr). For 260-SL-3 (65/35 SSMP/MA) a peak rate of 4,020 lb/hr (1,820 Kg/hr) was achieved. Gross blend

VI.C. Oxidizer Preparation (cont)

production rates (gross product produced/total run time) experienced during the processing of 260-SL-1, -2 and -3 were 2,790, 3,580 and 2,433 lb/hr (1,260, 1,620 and 1,100 Kg/hr), respectively. These rates are considerably below the peak rates, because the total run times includes down time for equipment repair, correction of feed problems, pacing oxidizer production with propellant production rates, and in the case of 260-SL-3, oxidizer blend adjustments.

The required production rate of blended oxidizer as a function of propellant production rate is presented in Figure 15. Considering the highest propellant production rate achieved, an average of 9,108 lb/hr (4,130 Kg/hr) operating two vertical batch mixers and the continuous mixer during the processing of 260-SL-2, it is seen that a rate of 6,300 lb/hr (2,860 Kg/hr) of blended oxidizer is required. As shown in Figure 16, this rate was not achieved even at the 24-hr peak oxidizer production rate. When only the vertical batch mixers are being operated, as seen in the summary of production data given in Figure 16 the oxidizer blend requirements are reduced. The average vertical batch mix production rate for 260-SL-2 was 5,790 lb/hr (2,620 Kg/hr) of propellant requiring 4,000 lb/hr (1,810 Kg/hr) of oxidizer (70/30 SSMP/MA), which exceeds the gross average rate of approximately 3,600 lb/hr (1,630 Kg/hr) achieved. The slower 4,512 lb/hr (2,040 Kg/hr) propellant production rate for 260-SL-3 required approximately 3,200 lb/hr (1,450 Kg/hr) of oxidizer (65/35 SSMP/MA, which exceeds the 2,400 lb/hr (1,090 Kg/hr) gross rate achieved.

From the above analyses it is apparent that the current oxidizer preparation facility does not have a production capability sufficient for meeting the propellant production rate requirements. The propellant requirements to date have been met by initiating the oxidizer grinding operations prior to propellant mixing. For 260-SL-2, 608,000 lb (275,000 Kg) of oxidizer was preground, and 258,000 lb (117,000 Kg) of oxidizer was preground for 260-SL-3. Since oxidizer production was not pacing for either of these

VI.C. Oxidizer Preparation (cont)

production runs, and the oxidizer quality satisfactory, this approach is an acceptable alternative provided that the ground and blended oxidizer is not stored for more than 5 days.

It is estimated that a gross average production rate corresponding to 50% utilization of the MA mill capacity can be achieved for the period required for loading a full-length motor. Thus, 4,000 lb/hr (1,810 Kg/hr) of a 70/30 SSMP/MA blend and 3,400 lb/hr (1,540 Kg/hr) of a 65/35 blend could be produced with the existing grind station. The compatibility of these oxidizer production rates with the production rates for (1) the expected 260-FL continuous and vertical batch mixer production rates, and (2) the expected 260-FL vertical batch mixer rate was assessed. The 260-SL-2 propellant production rates, corrected for the longer batch mix cycle discussed in a subsequent section, were used, since they should represent realistic estimates of rates which could be achieved in processing a full-length motor. This assessment, summarized in Figure 17, shows that a 7,795 lb/hr (3,536 Kg/hr) propellant production rate cannot be supported with the current oxidizer facility, since the pregrinding requirement would cause the 5-day (120-hr) blend storage requirement to be greatly exceeded. The 4,476 lb/hr (2,030 Kg/hr) production rate from two vertical mixers can be supported with either a 70/30 or a 65/35 SSMP/MA blend. Based on this assessment it is concluded that the continuous mixer cannot be operated for processing of a full-length motor, unless the oxidizer production facility is expanded. The expanded facility would have to provide a production rate of approximately 5,650 lb/hr (2,560 Kg/hr).

Three methods for expanding capacity were considered: installing an MA mill in the existing HSMP section, installing a duplicate MA system, or installing a larger MA mill. The last was discarded, since the necessary equipment is not available.

VI.C. Oxidizer Preparation (cont)

The simpler and less expensive of the other methods is to replace the HSMP grinder (which would be kept as a spare for the SSMP grinder) with a new #8MA grinder. This will allow the utilization of the unground oxidizer receiver hopper and the grinder feed bin assembled without change. The fluidizer feed hopper can be relocated for use under a new MA dust collector. The major new equipment would be grinder, dust collector and fluidizer. The estimated cost of this modification is \$128,800. The drawback to this scheme is the loss of the redundant mikropulverizing system (HSMP) which might be required for future programs, or as backup to the SSMP system.

The alternative approach is to provide a complete new oxidizer grinding system without changing the HSMP system, as shown schematically in Figure 18. This will require the installation of a new oxidizer receiver hopper, grinder feed hopper, and fluidizing system. Building modifications will be much more extensive to install this equipment and there will be a tendency to overcrowd the area. The addition of a new system will require more complicated interlocking of controls and a more congested control panel. It will, however, maintain the full station capability for future programs, as well as retain a ready back-up for the SSMP grinder. The estimated cost for this modification is \$181,000.

The choice, then, is to weigh minimum cost against facility adequacy. Adequacy for this program includes not only the capability for processing and casting propellant for the nominal operating conditions, but also to provide adequate back-up capacity and processing flexibility for unplanned performance abnormalities. It is probable that a satisfactory propellant grain could be cast at the production rate obtainable with only the two vertical batch mixers. However, the probability for producing a high-quality, defect-free grain is greater if the cast rate, usually paced by production rate, is greater. Therefore, the full mixing capacity should

VI.C. Oxidizer Preparation (cont)

be supported by adequate oxidizer grind capacity. By doubling the MA output, that fraction of the blend would no longer be limiting for either a 70/30 or 65/35 blend ratio. However, the output from the SSMP system was examined and was found to be the limiting fraction if the MA capacity is increased as described.

If we assume 50% utilization of the SSMP grind capacity of 7,500 lb/hr, as estimated previously for the MA system, then the gross production rates of blended oxidizer would be 5,356 lb/hr (2,429 Kg/hr) and 5,769 lb/hr (2,617 Kg/hr) for blend ratios of 70/30 and 65/35 SSMP/MA, respectively, as indicated in Figure 19. Thus, the required use rate of 5,650 lb/hr (2,560 Kg/hr) can be maintained without a significant amount of pregrinding. This, of course, does not consider requirements for back-up capacity. If the option of installing a complete new MA system were selected, the back-up capability for the SSMP fraction already exists in the HSMP system, which could be operated at slow speed, thereby providing complete redundancy. If the HSMP system were to be reworked to an MA system, back-up capability could be provided partially by pregrinding and blending a portion of the required total of 2,480,000 lb (1,125,000 Kg), or completely by pregrinding and storing the SSMP fraction only. Although there is little experience in storing SSMP powder for extended periods, the SSMP should be closer in storability to unground oxidizer than to the blended material, because of relative particle sizes. Assuming this to be the case, it is evident that, for the Task I requirements, the expansion of the oxidizer grind station capacity can be accomplished most expeditiously by installing an additional MikroAtomizer system in the place of the existing High Speed MikroPulverizer system.

3. Oxidizer Sampling and Testing

Current oxidizer test methods are not sufficiently definitive to permit assessment of the adequacy of the current sampling method. In the

VI.C. Oxidizer Preparation (cont)

current facility the ground product bins are sampled by means of a thief in the side of the bin, and classified by screen analysis. There are no generally accepted tests which could be substituted without experimental verification.

New oxidizer test methods which give meaningful correlations with propellant burning rates should be developed. Methods considered should include particle-size distribution by sedimentation (Mine Safety Appliance Apparatus) and micromerograph. Measurements of the fine fractions of the SSMP ground oxidizer as well as the MA fraction should be evaluated. Burning rate measurements of sample propellant simulants (oxidizer and an oil) should also be evaluated.

D. PROPELLANT MIXING

1. Vertical Batch Mixers

a. Description

The two Regal 300-gallon (1.13 m^3) vertical batch mixers, manufactured by the J. H. Day Co., have been used to process hundreds of 5,500 lb (2,500 Kg) batches of composite propellant for the 260-in. (6.6m)-dia short-length motors. Premix is dispensed into the mix bowl at the Fuel Preparation Building. Oxidizer is dispensed from a pre-weighed carboy after completion of oxidizer addition. The propellant is then mixed under vacuum.

b. Production Rate

The average batch cycle times for each of the three 260-SL motors is shown in Figure 20. The cycle time varies from a low of 116

VI.D. Propellant Mixing (cont)

min/batch for 260-SL-2 to a high of 162 min/batch for 260-SL-1. The increment of the cycle where the greatest time savings were effected for these two series of batches was in the length of time between start of batch to bowl-up, 58.5 vs 37.3 min, resulting from improved handling equipment and procedures, and probably an increase in the skill of the operators. A similar time savings was effected in the interval between batches, 2.6 vs -18.5 min, the negative figure for 260-SL-2 representing operations accomplished during a batch which were required for the succeeding batch. The batch cycle time for 260-SL-3 was intermediate between SL-1 and SL-2, 147 min/batch. The interval between bowl-up and bowl-down for SL-3 was 102 min compared to 87.5 min for SL-2. This increase was due partially to an increase in the final mix cycle on SL-3 from 20 to 30 minutes and partially to greater difficulty in adding oxidizer (hang-up, etc.) on SL-3.

For casting of a full-length motor, an average batch cycle intermediate between 260-SL-1, and -2 would appear most likely i.e., approximately 140 min, except that based on the results of the Propellant Improvement Program, incorporation of an additional 10 min vacuum mix between oxidizer addition and final fuel addition would be required. Thus, a reasonable estimate of the average batch cycle would be 150 min, slightly longer than for SL-3 but still significantly shorter than for SL-1.

The actual propellant production rate for a full-length motor from the VBM's could be significantly increased if the size of the batch could be increased, e.g., from 5,500 lb (2,500 Kg) to 6,000 lb (2,720 Kg). This batch size appears perfectly feasible in view of the fact that more than one hundred 6,000 lb (2,720 Kg) batches have been prepared (of propellant less dense than ANB-3350) in the vertical batch mixers at ASPC which are the same configuration as the DCP mixers. The higher density of ANB-3350 propellant compared to ANB-3105 would permit an increase in the batch size from 5,500 lb

VI.D. Propellant Mixing (cont)

(2,500 Kg) to 5,600 lb (2,540 Kg) without an increase in the volume of propellant in the mixer. However, to accommodate the increased weight of oxidizer charged to the 6,000 lb (2,720 Kg) batch, the Aerojet-owned 74 cu ft (2.1m^3) Tote bins would have to be modified to 80 cu ft (2.26m^3). In addition, the deaeration capability of the mixers with the larger batch size would have to be proved in order to meet large motor casting requirements. This type of improvement is probably more appropriate to the Task II program phases.

A significant factor in the length of the mix cycle is the oxidizer addition time. For motor 260-SL-3, there was a full seven minute difference in the average length of the AP addition time between the North and South stations, attributed to an improved vibrator system in the North Station. For preparation of a full-length motor, the vibration systems in both stations would be thoroughly overhauled and additional vibrators installed where necessary.

Another problem encountered frequently during the processing of 260-SL-3 was oxidizer hang-up in the mixer addition chutes. For future propellant production in these mixers, a remotely operated nitrogen jet(s) could be installed in these chutes to eliminate this problem by blowing oxidizer remaining in the chute into the mix bowl. Other possibilities would be to polish the internal surface of the chute and to replace the bellows connection to the Sweco screen with a straight-sided flexible connection. The success of, or problems induced by, any of these modifications would have to be determined experimentally.

Vacuum System

The modifications necessary to improve the vacuum systems in the vertical batch mixers would consist principally of plumbing circuit

VI.D. Propellant Mixing (cont)

changes, as shown in Figure 21. The pressure transducer would be mounted in a spare port in the mixer head to provide direct reading. By separation of the shroud vacuum line from the nitrogen supply line with a filter to avoid ingestion of powder, the system would be comparable to the VBM setup at ASPC, which has performed very successfully. In addition, a cleanout port would be provided in the mixer vacuum line. The estimated cost of these changes is, \$3,500.

2. Continuous Mixer

a. Description

The Continuous Mix Facility, based on a Baker-Perkins UK-200 Ko-Kneader, is a sophisticated system specifically designed for high-rate production runs. The mix capacity varies from 1,000 to 6,000 lb/hr (450 to 2,700 Kg/hr), depending on solids requirements, but usually is operated at 4,000 lb/hr (1,810 Kg/hr) for 260-in. (6.6m)-dia motor propellants. The premix and final fuel are metered into the stream from storage tanks. The oxidizer is transferred from loading bins by a fluidizer system to a weighed belt feeder metering system, from which it is transferred by screw conveyors to the mixer. The mixer output flows into a surge pot and then through a Baker-Perkins RotoFeed for deaeration and pumping to the loading area for filling into transfer pots.

b. Assessment of Capabilities

Based on the similarity in the processing characteristics of ANB-3105 and ANB-3350, it would be expected that the continuous mixer could be operated for preparation of propellant for a full-length motor under conditions comparable to those used for 260-SL-1 and -2. The difficulties

VI.D. Propellant Mixing (cont)

encountered while attempting to produce ANB-3254 propellant were related to the flow properties of that specific formulation prior to deaeration, and would not be expected to recur within the processing guidelines established by Contract NAS3-12002.

Although some difficulty was experienced with the oxidizer addition system of the continuous mixer during the processing of motors 260-SL-1 and -2, modifications to effect any significant improvements would be extensive and would not be justified for a single motor program.

The capability of the continuous mixer to provide adequate deaeration of the mixed propellant would have to be determined, on the basis of low-shear viscosity criteria, during the activation phase of a motor-loading program.

E. RAW MATERIAL REQUIREMENTS

Figure 22 lists the approximate totals of each of the raw materials required to insulate and cast a full-length motor assuming the use of the improved propellant formulation ANB-3350. A total of over 500 Tote bins of oxidizer would be required, assuming 5,000 lb (2,270 Kg) per Tote bin, for which there is adequate capacity on the oxidizer storage pad at DCP.

The various additives (iron oxide, Iron Blue, PBNA, etc.) normally available in 50 lb (23 Kg) bags would be purchased pre-dried and in steel drums. A survey was conducted to determine if there is sufficient storage space under cover for these as well as the 925 drums of aluminum powder and 58 drums of DER-332 required. Previous experience has indicated that steel drums cannot be stored outdoors. Most of the necessary space for the approximately 1250 drums would be available in the premix hold rooms at the vertical mix stations.

VI.E. Raw Material Requirements (cont)

Otherwise, it is assumed that sufficient storage space would be available at leased warehouse facilities in Homestead.

The 44,000 gallons (167m^3) of PBAN terpolymer and the 16,500 gallons (62m^3) of DOA plasticizer would be received in from 4 to 8 railway tank cars depending on the size. The rail siding previously used at Homestead would be adequate. However, it should be noted that the warehouse and rail siding are no longer under lease by Aerojet and their availability in the future is unknown. However, other facilities in the Homestead-Florida City area might be available.

F. PROPELLANT SAMPLE CURING

It is expected that carton samples would be obtained at the rate of two cartons for each vertical/mix batch and four cartons for each continuous mix pot. Assuming 5,500 lb (2,500 Kg) for each batch on a batch cycle of 2.5 hours for both vertical mixers and 7,500 lb (3,400 Kg) for each CM pot at an average production rate of 3,320 lb/hr (1,500 Kg/hr), a total of 378 VBM batches and 209 CM pots (including losses) would be required to cast the motor. A corresponding total of 1,592 carton samples would be obtained. In addition, six additional carton samples would be obtained from every sixth CM and VBM pot for long-term and specialized tests, resulting in 594 additional cartons, or a total of 2,186 cartons per motor.

The existing cure oven at the Qualification Motor Processing (QMP) building contains 36 lineal feet (11.0m) of six-high shelving 18 in. (46 cm) deep with an estimated capacity of 1,386 cartons. By arranging additional free-standing shelves, the shelf capacity can be doubled (to 2,772 cartons), while maintaining a 3-ft (0.9m) aisle width and free access to all doors. This addition also would have adequate space to accommodate additional propellant

VI.F. Propellant Sample Curing (cont)

samples as might be required, such as burning rate motor grains. The estimated cost of the shelving is \$2,500.

G. PROPELLANT CASTING

1. Description

The 260-FL motor would be cast with the bayonet casting process, as were the 260-SL motors. In this process, 6-in. (15 cm)-dia reinforced rubber tubes are inserted into the chamber to the forward head, as shown for the full length motor in Figure 23. Propellant transfer pots are connected to the top of the bayonet tubes. Initially, the tubes are plugged at the bottom. The tubes are then evacuated, and propellant flow is started by pressurizing the transfer pot with nitrogen and opening the pot valve. The propellant forces the plugs out of the tubes, after which the plugs are removed from the chamber. Each propellant pot is removed when empty and replaced with a full pot. The ends of the casting tubes remain immersed in the propellant cast in the chamber. At intervals, each casting tube is removed from the chamber and shortened. The shortened tubes are then reinserted with the end immersed below the surface of the propellant in the chamber. When the chamber is full, the casting tubes are removed, and the chamber is sealed until the completion of propellant curing.

2. Special Requirements

In the evaluation of casting requirements for a full-length motor, the two major criteria to be considered are the limitation of bayonet tip submergence to 18 in. (46 cm) and the necessity for controlling propellant surface flow path length around the relatively complex 12 fin core configuration shown in Figure 23.

VI.G. Propellant Casting (cont)

To accomplish the objective of minimizing bayonet submergence, some capability for adjusting the bayonet height must be incorporated to avoid the otherwise excessive frequency of cutting the bayonet. Even without considering the special requirements of casting the forward end fins, this would be a pacing item during casting. Two types of adjustable casting stands were considered, along with two methods of adjusting the bayonet with a fixed casting stand.

One type of adjustable stand is that used for casting motor 260-SL-1. Each stand was individually adjustable in height to four feet (1.2m) using air-driven jack screws. One of the disadvantages of this design was the requirement for raising each pot to the top of the stand. This was time-consuming and contributed to excessive use of the 20-ton (18,400 Kg) bridge crane. Another disadvantage is the risk of suspending the pots over the motor.

Another type of adjustable casting stand would be one which traverses horizontally, with the bayonet tubes guided through the 90-degree (1.57 rad) bend on roller tracks. This system is particularly attractive from an operational standpoint, since the position adjustment is limited only by the length of track on which the casting pots travel. The principal disadvantage is that the bayonet tubes which have been employed on all 260-in. (6.6m)-dia motor castings can not be operated through any reasonable bend radius, because of the steel reinforcing straps. A new type bayonet using more flexible reinforcement or external supports would have to be developed. In addition, the existing movable building is not large enough to use this concept effectively.

A low-cost approach would be to incrementally raise the pot and bayonet stands using spacers. This approach was used on the Propellant

VI.G. Propellant Casting (cont)

Improvement Program, Contract NAS3-12002, with up to 12 in. (30 cm) of shims. A more sophisticated system could provide greater adjustment, possibly using spacers under the entire cast stand. The principal disadvantage to this approach is that the pots have to be placed on the stand with the crane, similar to that required with the 260-SL-1 type adjustable stands.

Another low-cost approach would be to employ a number of spacer tubes at the top of the bayonet, to be removed singly to provide the adjustment feature. This would involve a significant amount of assembly time, but would allow the use of the existing cast stand setup.

As discussed previously in VI.A.3, bayonet casting with the 12-fin core will require placement of a bayonet between each fin to assure adequate propellant distribution over the casting surface. Several approaches were considered, including casting each pot at one location, casting with three bayonets at a time in each quadrant, and casting with 12 bayonets flowing simultaneously. In order to assure complete adequacy of the propellant grain, the last approach was selected, even though the tooling and operational requirements are the most demanding.

To cast through each bayonet simultaneously some degree of manifolding would be required, since 12 pots of propellant could not be available for casting at the same time. The manifold arrangement must be efficiently arranged to balance flow rates and also must consider the approach used to provide bayonet height adjustment. Supplying all 12 bayonets from a single manifold provides some options on the number of pots being cast simultaneously, but operational considerations indicate that the manifolding of three or four bayonets would allow more flexibility in scheduling bayonet cutting.

The plan selected for casting incorporates the following features:

VI.G. Propellant Casting (cont)

- a. Use the existing cast stand and modify as required.
- b. Manifold four bayonets to each casting pot. This arrangement would be necessary only for casting the forward fins.
- c. Adjust bayonet height using spool sections below the manifolds, and adjustable bayonet stands.
- d. Install an additional 5-ton (4,500 Kg) auxiliary hoist to support more frequent bayonet cutting.

The selected design, shown conceptually in Figure 24, utilizes four bayonet manifolds to accommodate the existing, three-pot cast stand, and requires the use of spools (tube spacers) and an adjustable bayonet stand to adjust the bayonet tip location. In order to provide working room, either the aft end of the motor would have to be five feet lower than the short-length motor position, or the cast stand would have to be raised five feet. Since the lower position for the motor aft end would necessitate relocation of the lateral restraints on the caisson wall, it would be less expensive to provide the footings shown for the cast stand.

The following items of equipment modification or addition would be required:

- Tube Spacers, 72 ea min
- Manifolds and Brackets, 3 ea
- Keystone Valves, 12 ea
- Bayonet Stands, 12 ea
- Pinch Clamps, 12 ea
- Casting Cover Modification
- Casting Stand Modification
- Additional 5-Ton Auxiliary Crane

VI.G. Propellant Casting (cont)

The estimated cost of these items is \$107,100, and may be compared with the approximately \$125,000 spent on the adjustable cast stands for 260-SL-1.

The bayonet design used for the 260-SL motors would be adequate for this application, but demonstration in the required length of structural integrity and pressure drop would be necessary. The estimated cost of fabrication and testing of two 120-ft (37m)-long prototypes is \$9,700. The estimated procurement cost of the bayonets is \$20 per ft (\$66 per m).

3. Environmental System

Modifications to the environmental system at the CCT will include a 500 in. (14m) extension of the 34 in. (0.86m) supply ducting to the bottom of the enclosure, at an estimated cost of \$9,100. The existing cylindrical shroud is too small in diameter to be incorporated into a shroud for a full-length motor with its larger handling rings. The estimated cost of the new shroud is \$150,000. It is possible that this figure could be reduced by a different type of construction or by salvaging the existing shroud. The existing shroud adapter can be modified for approximately \$6,000. No modifications to the heating and air conditioning systems for this program would be required, since the only penalty would be an increase in chamber preheat and grain cooldown transient times. Any significant improvement in capacities would necessitate a complete redesign and replacement of the existing system.

VII. STATIC TESTING

The following assumptions or ground rules were made which influence the final estimate and facility/equipment requirements:

- The 260-FL ignition system would be either fore-end mounted or fly-away (non-restrained) aft igniter motor.
- Supporting systems for both a LITVC and movable nozzle would be considered.
- A checkout fixture for the nozzle-mounted TVC components would be required.
- The motor quench system and flight retention hardware design criteria would be essentially the same as for Motor 260-SL-3.
- No significant control or terminal room structural modifications would be made.
- A digital recording system is highly desirable.
- Side forces would be measured; a limited static and dynamic stand calibration would be conducted.

A. INSTRUMENTATION AND DATA ACQUISITION

The basis for this portion of the study is a data requirements summary (Figures 25 and 26) which lists each measurement or data channel which is envisioned for a 260-FL motor test with either movable nozzle or LITVC. Aft-end ignition and STE systems similar to the 260-SL tests are assumed. The projected number of channels required for each type of measurement is listed below. The number of existing circuits, less signal-conditioning equipment, is noted in parentheses.

VII.A. Instrumentation and Data Acquisition (cont)

<u>Type Measurement</u>	<u>No. Channels</u>	
Strain gage	60	(36)
Position monitoring	20	(8)
	36	with LITVC
High frequency	12	(12)
Temperature	60	(24)
Voltage and/or current monitoring functions	40	(24)
<u>Control Circuits</u>		
Motor and STE	30	(8)
Cameras	9	(9)
Television	3	(2)

To attain the desired data acquisition capability, various approaches were investigated. These consider different modes of equipment procurement (buying, borrowing, rental, etc.) and were directed toward the Task I objective of economy and minimum modification to existing facilities or equipment. The results of the instrumentation system survey are summarized in the subsequent paragraphs.

1. Cabling

The existing DCP instrumentation cables are assumed to be in satisfactory condition. Despite the temporary nature of their original installation, the cables themselves will survive their environment for an indefinite period unless their outer protective sheathing is punctured. No problems were encountered during the four years between installation and the 260-SL-3 test. To bring the transmission capacity up to program requirements, two additional 12 channel 6-wire cables would be installed. This would provide the 60-channel strain gage system needed. One 40 channel cable of shielded-pairs is also planned. Cost of acquisition, installation, termination and checkout of the

VII.A. Instrumentation and Data Acquisition (cont)

additional cables is the most significant item in this category. The lack of sufficient thermocouple channels would be overcome as in the past by the use of sampling techniques.

2. Signal Conditioning

Most signal conditioning equipment (amplifiers, power-supplies, calibrating resistors, switching-units, etc.) probably would be available from either Aerojet-owned or terminated government contract inventories. Several Aerojet Sacramento test facilities have been inactivated in recent months, providing a surplus of these items. However, their availability in 1970-71, or later, cannot be depended upon. For cost estimating purposes, it was assumed that only minimum requirements exist in this area.

3. End-Recorders

a. Oscillographs

No problems are anticipated in acquiring the cost-free use of six oscillograph recorders over a 2 to 3 month period.

b. Strip Charts and Visual Indicators

Approximately four of each type instrument would be available on a no-cost loan basis.

VII.A. Instrumentation and Data Acquisition (cont)

c. FM Magnetic Tape Recorder

A 14 channel Ampex tape recorder would be available at no cost to the contract. A 32 channel recorder, such as the FR-1200 used on the 260-SL-3 test would be preferable; however, none is available at Aerojet.

d. Analog-to-Digital Converter and Recorder

A 50 channel Aerojet-designed-and-built ADC system, presently owned by an AF Contract, is expected to be available during the assumed 1971 test program period. Only installation and checkout costs would be incurred.

4. Control Systems

Programmed commands to the TVC servovalves would be recorded on magnetic tape and transmitted to the TVC control unit. A suitable tape deck is not available and would have to be rented. Other control room components of the TVC command system, such as the buffer and isolation amplifiers, would be assembled from existing equipment.

It has been decided that the past procedure of using manually actuated countdown operations would be continued for the single motor 260-FL test program. Although an automatic sequencing unit would probably be available, the cost of removal from its present location, re-installation and checkout is not justified for a single test.

VII.A. Instrumentation and Data Acquisition (cont)

5. Transducers

All required pressure transducers, accelerometers and position measuring sensors would be provided from the Aerojet instrument pool. The 260-FL contract would assume any calibration and posttest repair (if applicable) costs as direct test charges.

The three five-million lb (22,200,000) capacity load cells used on the previous 260-SL tests would again be used. Side force measurement load cells of the required load capability are not available at Aerojet and must be purchased. Current prices for the three 500-K (2,220,000N), two 100-K (445,000N), and one 250-K (1,110,000N) load cells which comprise the side force measurement and calibration system are included in the cost summary.

6. Miscellaneous Systems

All required circuitry and controls for the motion-picture cameras and two TV channels are installed or available. High-speed cameras are expected to be available on a no-cost loan basis from the owning AF contract. Electronic components and cabling for a third TV channel are available. A multi-channel electronic reference junction for the thermocouple system is recommended to replace the ice-water bath now employed.

7. Control Room

Although no physical modifications are proposed for the instrumentation center and control room facility, it must be recognized that the addition of an ADC unit (two instrument-bays wide) and the TVC programmer and control system (one bay wide) would reduce substantially the already minimum working space. At least one of the two desks would have to be relocated

VII.A. Instrumentation and Data Acquisition (cont)

outside of the control room. The possibility of locating the ADC and TVC control console in a trailer adjacent to the control room was considered. However, it is felt that the inconvenience of the crowded control room is preferable to the operational problems which would result from having the basic data acquisition and control system isolated from the balance of the instrumentation system and the test technicians. The cost of running cabling from the control room to the trailer was also a factor which makes this plan less desirable.

8. Outside Test Lab Option

A quote was received from Datacraft, Inc., for the rental for six weeks of a completely equipped instrument trailer and the services of one maintenance technician. This unit would relieve Aerojet from having to purchase, rent or borrow any component and would include oscillographs, a digital and analog tape recording system. The Datacraft cost was adjusted to include the routing and termination of all cabling from the control room to the trailer and compared to the Aerojet expense of component procurement, calibration, preparation for shipment and unpacking. The results indicate no cost advantage in the Datacraft approach as nearly all required equipment will be available at Aerojet, Sacramento, and may be shipped GBL to DCP. In addition, there are distinct operational advantages to the continued use of the present control center. The single largest cost item in the instrumentation area is the installation of the additional data channels requiring new cabling. This expense will be incurred regardless of who supplies the signal conditioning and end-recording equipment.

VII. Static Testing (cont)

B. MODIFICATIONS TO CCT AND ASSOCIATED EQUIPMENT

The 260-FL motor is approximately 47 ft (14m) longer than the previously tested SL motors. Therefore, in order to maintain the motor aft flange at the same elevation as before, some major alterations must be made to the CCT and particularly to the T-460020 thrust adapter, or spacer, now installed in the facility. These modifications are discussed below:

1. Cast/Cure/Test Facility

a. Horizontal Load Reaction Pads

Two structural plates, one each on the east and south wall of the caisson at the -96 ft (-29.3m) level, and identical to those presently located at the -48 ft (-14.6m) position, must be installed. These pads serve as the mounting support and load reaction system for the forward horizontal side force measurement assemblies. The installation would consist of anchoring eight 3-in. (7.6 cm)-dia threaded J-Bars to existing reinforcing rods in the concrete caisson wall. A 4-in. (10.2 cm) thick steel plate would be secured to the anchor bars.

b. Lower Platform Relocation

Seven platform support structures would be installed in the caisson wall at the -107 ft (-32.6m) elevation. Design of these items would be identical to those presently installed at the -62 ft (-18.9m) level. The installation procedure would be similar to the horizontal load reaction pads. The existing work platform would be positioned at the lower level after these supports are in and the thrust adapter modification is completed.

VII.B. Modifications to CCT and Associated Equipment (cont)

c. Utilities Relocation

All electrical, pneumatic, lighting and alarm capabilities or equipment presently located at the -60 ft(-18.3m) level must be extended to the -105 ft(-32.0m) elevation platform.

d. Elevator and Staircase Modification

Minor structural alterations would be required on the spiral staircase to permit exit/egress capability at the relocated platform. The elevator control system must be modified to provide automation stopping at the lower level.

e. Igniter Tower-Linkage Mounting Pad

The steel plate located on the top, eastern, edge of the CCT, used to support the igniter tower actuation and linkage assembly, was pulled from its concrete anchoring on the 260-SL-3 test. The initial installation was designed for compression forces only and was unable to withstand reversing loads as the tower oscillated at completion of the retraction cycle.

The plate now installed would be removed and concrete removed as necessary to expose caisson reinforcement bars. A new steel plate would be structurally tied to the existing reinforcing members and new concrete poured in place. This anchoring system would be designed to withstand both tension and compressive loads. This modification is only necessary if aft end ignition is used.

VII.B. Modifications to CCT and Associated Equipment (cont)

f. Mounting Pad for Nozzle Checkout Stand

A 16 ft(4.9m) square steel plate, 2-in.(5cm) thick, will be anchored to a 2-ft(0.6m) thick reinforced concrete pad for mounting of the nozzle bench-test fixture. All pretest nozzle/TVC system assembly, alignment and most functional checkout operations will be conducted at this location.

g. Hydraulic Power Supply Unit Pad and Enclosure

A reinforced concrete enclosure for the hydraulic power supply unit is required. This structure would be located at the edge of the asphalt apron, near the stiffleg derrick. It would provide a weather cover, protection from minor motor or nozzle malfunctions and reduce the ambient sound level of the CCT area during TVC system checkout operations. Electrical power, water cooling and control circuits would be provided at the site for back-up to the power unit. This facility would not be required if a LITVC design is selected for the 260-FL motor.

h. Foundations and Support Structures of LITVC Tanks and Piping

Concrete foundation and footings would be needed to support the injectant supply tank, GN_2 pressurization tank and main supply lines. These structures would be located at the south edge of the CCT facility.

C. SPECIAL TEST EQUIPMENT MODIFICATIONS OR ADDITIONS

A preliminary layout drawing of the 260-FL reference motor in the test configuration was prepared and is shown in Figure 27. From review of the test requirements, motor/STE installation, and cost and/or operational tradeoffs the following system requirements and engineering approach have been established.

VII.C. Special Test Equipment Modifications or Additions (cont)

1. Thrust Adapter

A section of the T-460020 thrust adapter must be removed to accommodate the added 260-FL motor length. Approximately 47 ft(14m) would be cut from the center section starting at 6-ft(1.8m) above the caisson floor level and ending in the 6th circular segment. All joints in the adapter are welded which increases the scope of the modification operation. Various plans were considered for performing the section removal and reassembly.

The approach selected offers the least complicated operation, least expense and the option to reuse the adapter in the SL motor configuration. The main features of the planned method are:

- Make first cut with friction saw at upper level, shimming behind cut as necessary to support weight of cut section.
- Remove upper section and install positioning and fastening brackets or angles.
- Make lower cut in same manner as first cut; remove middle section and place in storage.
- Secure positioning and tie-down brackets to lower section joint interface.
- Mate the two sections so a 360-degree (6.28 rad) butt joint at the cut interface is established.
- Secure the two sections with a bolted joint on both the interior and exterior brackets (see Figure 28).

VII.C. Special Test Equipment Modifications or Additions (cont)

This scheme eliminates any above-deck rotation, weld surface preparation or extensive welding. By proper sizing of brackets and bolts, the original adapter strength may be achieved or even exceeded when the reduced column length (lower L/D ratio) is considered.

2. Thrust and Side Force Measurement System

No modifications to the thrust ring or 5 million lbf (22,400,000N) load cells are required. Various flexure systems were considered for the axial cells which would provide the lateral and rotational flexibility needed for a multicomponent thrust stand. The universal-type flexure, used on most smaller test stands, is not feasible from either a technical or cost standpoint. The largest such units manufactured to date have been 3 million lbf (13,400,000N) capacity, and have cost over \$30,000 each. The ability to achieve a satisfactory heat treat in the center of the steel block from which the flexure is machined has not been demonstrated, causing a de-rating of the units' load carrying capacity. This problem would be even more pronounced on a 5 million lbf (22,400,000N) flexure.

Shroud flexures are finding acceptance in large motor test facilities and have a definite cost advantage over universal-type flexures. The LPC 156-in.(4.0m)-dia motor test stand uses this type flexure rated at 1.5 million lbf (67,000,000N). Cost of this installation was about \$80,000 and represents the largest units of this type made to date. A rough estimate of \$120,000 for a similar flexure system for 260-FL motor testing was given by Ormond, Inc., who have designed and fabricated all of the large units now in service.

VII.C. Special Test Equipment Modifications or Additions (cont)

A new concept of axial load cell isolation was conceived and is proposed for use on the single motor program. This system takes advantage of the low shear modulus of the General Tire & Rubber Company Gen-Shear 44125 natural rubber, also used in nozzle flexible seals. Two layers of 0.20 in. (0.51 cm) thick rubber would be incorporated in a laminated steel/rubber pad and installed between the load-cells and the thrust ring (see Figure 29). The rubber would be subjected to a maximum compressive stress of 3,500 psi (2,400 N/cm^2) due to motor weight and thrust. Test data has indicated little or no effect on the rubber shear modulus with up to 2000 psi (1,380 N/cm^2) compressive stress imposed, the upper limit of the test apparatus. Fabrication and operational functions would be considerably less complicated and the cost about 15 to 20% of a comparable shroud flexure. The stiffness under load of a 5.0 million lb (22,200,00N) shroud flexure is estimated by Ormond to be approximately 197,000 lb per in. (22,200 N/M) of lateral movement. The lateral restraint of a laminated isolation pad is calculated to be 68,800 lb per in. (7,770 N/M). Assuming a maximum lateral displacement at the pad (due to deflection of the horizontal load cell flexure string) of 0.040-in. (0.18 cm), a restraining force of only 2,750 lb (12,200N) per axial support is produced or 8,250 lb (36,700N) for the three load cell array. This is an important consideration as the magnitude of the side force reaction at the lower level is under 40,000 lbf (178,000N).

The horizontal force measurement system would use universal flexures on either side of each load cell. The upper pair of reaction-measurement assemblies on the east-west axis would each have two 600-K (2,700,000N) flexures and a 500-K (2,200,000N) load cell. This combination provides a 2:1 safety factor on the expected maximum side force when the flexure is deflected to 2-degrees (0.035 rad); the flexure is derated to 45% of its rated capacity at 2-degrees (0.035 rad). The single north-south assembly would have two 1 million lbf (4,450,000N) flexures and a 500-K (2,200,000N) load cell and would

VII.C. Special Test Equipment Modifications or Additions (cont)

provide the same structural margins. The lower level flexure/load cell combinations would use 150-K/100-K (670,000/445,000N) rated components respectively, as the expected side forces are only about 31,000 lbf.

The proper selection of flexures, careful design and installation of the system and the pre- and in-test calibration of the motor/stand assembly would enable reduction or elimination of the most common static error terms associated with the measurement of multicomponent thrust data. These errors include:

- Hysteresis, friction and slop (free-play)
- Test stand redundancy
- Interactions resulting from initial misalignments
- Interactions resulting from axial deflection of members under load

The concept of using a 3-load cell array for motor support and axial thrust measurement is completely feasible and consistent with what is being used throughout the industry. The measurement of the six components of force allows solution of the six static equations associated with restraining a body in space. While a single point support system simplifies somewhat the solution of the side force resolution, the same basic error factors are present as are encountered on any multicomponent test stand.

Mr. A. N. Ormond, founder and owner of Ormond, Inc., is recognized as one of the country's leading authorities on the design and analysis of multicomponent thrust stands. Most precision force measurement systems now in use have been designed and built by Ormond, Inc., or incorporate flexures made by them. Mr. Ormond has reviewed the proposed DCP test stand system and agrees that axial and side force data may be obtained well within state-of-the-art limitations. The LPC 156-in.(4.0m)-dia test stand incorporates six

VII.C. Special Test Equipment Modifications or Additions (cont)

700-K (3,000,000N) axial load cells with Ormond, Inc. shroud flexures spaced equidistant around the thrust ring and universal flexures at each end of every lateral load cell assembly. Axial and side impulse recorded during the 156-6 motor test was within 1.0 and 5.0% respectively of the predicted values⁽¹⁾ which attests to the ability to acquire acceptable performance data with a comparable ballistic test stand. An error analysis of the side force data measurement system by Ormond, Inc. revealed a maximum thrust vector resolution error potential of $\pm 3/4^\circ$ (0.013 rad) using a motor/stand calibration for data correction.

UTC uses four axial load cells for their test firing of 120-in. (3.0m)-dia motors. A data system error analysis⁽²⁾ claims force measurement accuracy of 0.3% and 1.5 to 3.0% (depending on the axis) respectively for axial and side loads.

A study of force measurement accuracies expected from the DCP three cell set-up using various axial transducer isolation devices was made for a 260-SL LITVC motor proposal in 1965. With shroud flexures, the axial force measurement accuracy was determined to be -0.2% bias with a $\pm 1.23\%$ repeatability. Side force accuracy was calculated to be -5.70% bias with 0.44% repeatability. The side force data accuracy should be at least that good with the use of the laminated isolation pads and even better if a side force calibration force is applied during the test firing. This procedure would be incorporated, as it can be accomplished for a fairly small additional expenditure while providing significantly more confidence in the test data.

(1) Report AFRPL-TR-66-109, 156-in.-dia Motor LITVC Program, July 1966 Lockheed Propulsion Company.

(2) Report ER-UTC 65-64, Error Analysis, United Technology Center, 13 April 1965.

VII.C. Special Test Equipment Modifications or Additions (cont)

The need for a side force data accuracy better than 3 to 5%, especially for a single motor test, is questionable and may be obtained only at a considerable expense and by extending the state-of-the-art in isolation systems. In a movable-nozzle type TVC system, the actual position of the nozzle may be precisely measured at all times allowing calculation of the expected side force vector. The measured side forces would serve to confirm the theoretical values and to permit calculation of the true nozzle-centerline thrust.

A motor incorporating a LITVC system should be tested under conditions which would result in the best possible force measurement accuracy. The measurement of side force data is the only way of resolving the location and magnitude of the resultant thrust vector, as the force-to-injectant flow rate relationship may vary from the theoretical for a number of reasons. This relationship is one of the important performance parameters which must be defined from the measured force data. To improve data accuracy, a more extensive stand calibration would be necessary along with precision stand alignment techniques. No variation in the vertical or horizontal load cell/flexure arrangement from that described for a movable nozzle would be proposed for a LITVC motor test.

The longitudinal length of the 260-FL motor between the lower and upper horizontal restraints is so long, over 1,170 in. (35.7m), that the angular misalignment resulting from deflections of the load cell strings or initial misalignment of the motor or stand is extremely small. For example, a 0.100 in. (0.25 cm) out-of-level condition of the thrust ring displaces the motor centerline only 0 degree, 1 ft, 20 in. (3.57×10^{-4} rad). The same condition exists at the lateral load cell/flexure strings, where the overall length of the assembly in relation to the maximum vertical displacement limits misalignment angles to 0 degrees, 5 ft (1.45×10^{-3} rad) or lower. This may be reduced even more at the upper level by pretest vertical adjustment to compensate for expected motor growth in the axial direction. The smaller the angle,

VII.C. Special Test Equipment Modifications or Additions (cont)

the smaller the measurement errors caused by forces required to bend all the flexures and the resulting restraining moments. A comprehensive discussion of why side members should be relatively long and an analysis of errors which are present in any multicomponent test fixture may be found in NAVWEPS Report 8353, Design Criteria for Large Accurate Solid-Propellant Test Stands, June 1963.

In addition to the proposed 3-point motor support and thrust measurement system being satisfactory for all needed data acquisition requirements, it takes maximum advantage of the available equipment and transducers with minimum modification necessary to existing STE or facilities. A single point motor support is unfeasible for the following reasons:

- A thrust collector cone or structure to transmit the axial force from the motor skirt to the load cell and back to ground, designed for 15M lbf (67,000,000N) would be a very massive and expensive structure. Undesirable dynamic characteristics which would degrade the thrust measurement capability would be expected. The lower level work platform support structure and motor-jack arrangement which mounts on the adapter assembly (spacer) would have to be replaced. The adapter itself would be scrapped.

- There is no known isolation system (flexure) which could be employed effectively for a 3-cell array, mounted for single point loading and designed to withstand 15M lbf (67,000,000N). The capability to manufacture and calibrate a single 15M lb (67,000,000N) capacity load cell is not presently available and the funding necessary to acquire same is beyond the scope of this program.

VII.C. Special Test Equipment Modifications or Additions (cont)

3. Ignition System, Aft-End Mounted

The basic system design would be similar to that used on previous 260-SL motor tests with the exception that the igniter motor would not be restrained by cables and would be "launched" from a tower inclined at 10-degrees (0.17 rad) to the vertical. The changes to available hardware or new items of STE required are summarized below:

a. Igniter Support and Retention

A rather extensive structural A-frame assembly would be required to support the aft end igniter as the 260-FL exit plane (9:1 expansion ratio) would be about 20 ft (6.1m) above the beams spanning the caisson. The sled assembly would be widened and would require an extension section to position the igniter motor within the nozzle. There are no available or usable components from past tests which could be used on the 260-FL test.

b. Track Assembly

The existing track could be used with structural modifications. The wheel guides would be moved outboard 12 in.(0.6m) each to provide more stability and the tower mounting position or rotation point must be raised 9 ft(2.7m) above the previous installation elevation. This requires the incorporation of a spacer structure on each of the two 36 in.(0.9m) WF beams. The tower retraction linkage would be changed and the structural support members reinforced.

VII.C. Special Test Equipment Modifications or Additions (cont)

4. Ignition System, Forward Head Mounted

a. Aft-End Insertable

No new STE would be required for an igniter that would be lowered through the nozzle and bolted to the forward boss.

b. Forward Head Installation

An igniter installation fixture, capable of moving, positioning and raising the igniter into place on the forward boss would be required. In addition, the decking below the forward head of the motor must be modified to provide the clearance needed with the igniter in a vertical position.

5. Quench System

A system employing the dual CO₂ and water quench capability, as used on past tests, is planned. An extension section will be incorporated in each arm of the existing boom assembly to permit entrance and proper positioning in the larger 260-FL nozzle. A larger water supply pipe would be added and nozzles installed so as to direct a heavy water spray on the chamber interior surfaces. The CO₂ would be used at a higher pressure than previously for greater penetration depth and is expected to extinguish the posttest burning of insulation. The boom actuation system used previously is available with the exception of two 1-in.(2.5 cm)-dia cables destroyed on the 260-SL-3 test firing.

VII.C. Special Test Equipment Modifications or Additions (cont)

6. Flight Retention System

The double-torus (or doughnut) collar used on all previous 260-SL tests would not be adaptable to the movable nozzle or LITBC configuration. A more feasible method of securing the 12 4-in.(0.1m)-dia retention rods at the motor end has been devised. The use of a collar supported by the 36 WG beams presented numerous clearance and operational problems and this planned approach has been discarded. Instead, a series of 12 brackets, or retention structures, would be secured to the top face of the motor aft handling ring. Adequate clearance would be provided between the rods, which insert in holes on each bracket, and the mounting structure so that no appreciable restraining force would be transmitted to the motor during normal operation. Retaining nuts would be positioned on the rods aft of the upper bracket structure. The motor layout drawing, Figure 27, shows this new configuration. The structural strength of the retention system will develop the full 12 million lb (53,400,000N) capacity of the rods. A significant cost advantage over a separate collar assembly is realized.

7. TVC Support Systems

a. Movable Nozzle

A hydraulic power supply and distribution system is the main item required for a flexible seal nozzle assembly. Several variable volume pumps, having supply capacities from 50 to 110 gpm (1350 to 6930 cm³/s) are commercially available.

VII.C. Special Test Equipment Modifications or Additions (cont)

The maximum hydraulic power requirement for a 2-degree (0.035 rad) nozzle deflection at a slew rate of 3-degrees/sec (0.052 rad/s) has been determined to be approximately 73.5 gpm (4630 cm³/s). This is with the forward pivot point flexible seal design. Based on this requirement, a hydraulic power supply unit capable of 75 gpm (4720 cm³/s) was selected.

b. LITVC System

Nearly all major components of an LITVC ground support system should be available from government owned deactivated liquid rocket test facilities at Aerojet. Assuming any 260-FL program would authorize GBL shipment, only disassembly, packaging and re-installation charges would be accrued, plus some foundation work (previously discussed) and structural support tooling. Several 2,200 gal (8.3m³) stainless steel tanks with control, relief and miscellaneous valving are available for N₂O₄ or other injectant storage. A 20,000 scf (560 standard m³) GN₂ tank, rated at 5,000 psi (3,450 N/cm²) is also available. Injectant supply system piping, main control valves, and two 6-in. (15 cm)-dia flowmeters would be purchased.

A schematic drawing of the LITVC ground support facility is shown in Figure 30. All required components of the system have been determined and an inventory made of components available from inactive test facilities at Aerojet. The cost of removal, rehabilitation (where applicable), preparation for shipment and reinstallation and checkout at DCP has been defined, as well as acquisition costs for any new items needed. The injectant supply tank and pressurization system which is available will permit either a constant injectant pressure or a blow-down (declining pressure) approach, depending upon which type system is planned for the flight TVC system.

VII. Static Testing (cont)

D. COST SUMMARY

Total costs of the modifications and equipment described previously are summarized below for the various motor configurations considered.

1. Modifications to CCT Facility

Movable Nozzle TVC	
with aft end igniter	\$ 76,775
with fore end igniter	\$ 70,380
Liquid Injection TVC	
with aft end igniter	\$ 79,315
with fore end igniter	\$ 72,920

2. Modifications or Additions to STE

Movable Nozzle TVC	
with aft end igniter	\$300,660
with fore end igniter, forward installation	\$237,940
with fore end igniter, aft installation	\$225,940
Liquid Injection TVC	
with aft end igniter	\$435,940
with fore end igniter, forward installation	\$373,220
with fore end igniter, aft installation	\$361,220

3. Instrumentation and Data Acquisition System

Movable Nozzle TVC	\$ 96,160
Liquid Injection TVC	\$104,760

VII.D. Cost Summary (cont)

4. Totals

Movable Nozzle TVC

with aft end igniter	\$473,595
with fore end igniter, forward installation	\$404,480
with fore end igniter, aft installation	\$392,480

Liquid Injection TVC

with aft end igniter	\$620,015
with fore end igniter, forward installation	\$550,900
with fore end igniter, aft installation	\$538,900

VIII. MOTOR SUBSYSTEMS

A. IGNITION MOTOR PROCESSING

Equipment and facility modifications necessary to process a 260-FL ignition motor were derived. No effort was made to justify a head-end or aft-end ignition system since the processing requirements are the same for either concept.

Ignition motor propellants for the short-length motors were mixed and cast into tray-molds at the Sacramento facility, then shipped to DCP for installation and final assembly. Ignition motor designs for the full-length motor specify ANB-3350, which is the formulation derived as a result of the propellant improvement program, Contract NAS3-12002, although any formulation for a full-length motor would be suitable for the ignition motor. For ignition motor processing, this propellant can be obtained readily from lot qualification batches or from batches processed for motor loading.

VIII.A. Ignition Motor Processing (cont)

The 260-FL ignition motor configuration shown in Figure 31, 32, and 33 were assumed for this study. The two head-end ignition motor configurations reflect the two propellant loading methods considered; bottom casting and tray-mold casting. Figure 31 shows a head-end ignition motor configuration designed for propellant loading by bottom-casting. The dual chamber head-end configuration, Figure 32, is designed for secondarily bonding precured propellant slabs. This approach meets the Aerojet safety requirement that propellant slabs bonded into a closed-end chamber cannot be longer than 40-in. (1.0m). The aft-end ignition motor configuration for both bottom-casting or secondarily bonding precured propellant slabs is shown in Figure 33. Bottom-casting concepts for head-end and aft-end ignition motors are shown in Figures 34 and 35, respectively. The tray-mold propellant casting method considered was the same as that used for processing the 260-SL ignition motors.

A cost trade-off was prepared based on Sacramento costs. Assuming a requirement for an additional ignition motor for a ballistic performance verification test, the tray-mold casting concept is more economical, as summarized below.

	<u>Bottom Cast</u>	<u>Tray-Mold Cast</u>
Burdened Labor	\$11,818	\$ 6,964
Tooling	<u>27,750</u>	<u>12,400</u>
Total	\$39,568	\$19,364

Processing and assembly of the ignition motor boosters, also shown in Figure 32, would be accomplished at the Sacramento facility, then shipped to DCP for installation into the ignition system. The 260-FL ignition motor process flow sheet for a single-motor program is presented in Figure 36.

VIII.A. Ignition Motor Processing (cont)

To accomplish the foregoing process plan, the following facilities are required:

- approximately 600 ft^2 (56m^2) of floor space in an environmentally control area for ignition motor assembly.
- approximately 120 ft^3 (0.45m^3) of 135°F (57°C) oven space for propellant curing.

For the single motor program, the vertical mix stations or the oxidizer blend room of the continuous mix station provide the floor space required for ignition motor assembly. The 120 ft^3 (0.45m^3) of 135°F (57°C) oven space would be available in the Qualification Motor Processing (QMP) Building, if the propellant is taken from lot qualification batches or from a batch prepared specifically for the ignition motors. Use of propellant from the motor production run would necessitate curing oven space which would not be available because of cure sample requirements. The ignition motors would then be cured with the 260-FL motor using a make-shift shroud.

B. TVC SYSTEM ASSEMBLY AND CHECKOUT; MOTOR FINAL ASSEMBLY

Process plans for assembly and checkout of TVC systems and for motor final assembly are shown in the flow charts in Figure 37 (movable nozzle) and Figure 38 (liquid injection), and are outlined below.

1. Movable Nozzle TVC System

a. Assembly and Checkout of TVC System

- (1) Install throat-entrance section on assembly/test fixture.
- (2) Assemble flex seal to throat-entrance section.

VIII.B. TVC System Assembly and Checkout; Motor Final Assembly (cont)

- (3) Install closure-extension section to flex seal/throat-entrance subassembly after application and cure of IBT-insulation.
- (4) Secure nozzle/seal subassembly to base ring of assembly/test fixture.
- (5) Conduct leak test of seal assembly using 35-50 psig (24-34N/cm²) nitrogen-helium gas mixture.
- (6) Assemble nozzle extension section to throat-entrance subassembly.
- (7) Install servoactuators; establish and verify null position.
- (8) Install, connect, and leak test hydraulic system plumbing and components.
- (9) Install and calibrate TVC system control and monitoring instrumentation.
- (10) Conduct TVC system end-to-end functional checkout using programmed test duty-cycle.
- (11) Secure and thermally protect hydraulic and electrical components.

b. Motor Assembly and Leak Test

- (1) Install forward mounted igniter (if used), less booster assembly.
- (2) Install nozzle-TVC assembly on motor.
- (3) Install fore-end igniter booster and all pressure measuring instruments.
- (4) Conduct motor leak test using 35-50 psig (24-34 N/cm²) nitrogen-helium mixture.
- (5) Remove leak test closure.
- (6) Install exit cone.
- (7) Install aft-end igniter (if used), and weather cover.

VIII.B. TVC System Assembly and Checkout; Motor Final Assembly (cont)

2. Liquid Injection TVC System

a. Assembly and Checkout of TVC System

- (1) Install injectant valve housing on injectant manifold assembly.
- (2) Install previously flow-tested and calibrated injectant valves on manifold.
- (3) Assemble manifold subassembly to forward exit cone section.
- (4) Install forward exit cone/manifold subassembly on bench test fixture.
- (5) Leak test manifold and valves using 35 to 50 psi (24-34 N/cm²) nitrogen-helium mixture.
- (6) Install servovalve electrical control and monitoring harness.
- (7) Conduct dry-run (no flow) actuation duty-cycle to verify proper operation of control system and all valves.
- (8) Connect facility injectant supply lines to manifold; secure fluid collection and disposal system.
- (9) Using distilled water as the injectant medium, operate servovalves through the firing duty-cycle. Repeat as necessary to establish proper functioning of all components.
- (10) Secure and thermally protect all electrical components. Purge liquid distribution system and servovalves with dry nitrogen to drive out residual moisture.

b. Motor Assembly and Leak Test

- (1) Install forward mounted igniter (if used), less booster assembly.

VIII.B. TVC System Assembly and Checkout; Motor Final Assembly (cont)

- (2) Install nozzle throat/entrance assembly and leak test closure on motor.
- (3) Install igniter booster and all pressure measuring instruments.
- (4) Conduct motor leak test using 35-50 psig (24-34 N/cm²) nitrogen-helium mixture.
- (5) Remove leak test closure.
- (6) Install nozzle extension and forward exit-cone/LITVC subassemblies.
- (7) Install aft-exit cone assembly.
- (8) Install aft-end ignition system (if used), and weather cover.
- (9) Mate all LITVC electrical connections to facility cabling.

Note: All subsequent injectant servovalve functional testing will be done with no injectant flow.

IX. OVERALL PLAN

An overall plan was prepared to summarize and integrate the process plans for each of the major functional operations, and to identify all facility and equipment requirements. A process flow chart for full-length motor processing and testing is given in Figure 38. The sequence of operations is described in the following outline.

IX. Overall Plan (cont)

A. SEQUENCE OF OPERATIONS

1. Receive Case

- a. Off-load case and transporter from barge to dock on Canal C-111.
- b. Install tandems, move cast to General Processing Building.

2. Insulate Case

- a. Move case into temporary building and crib in place.
- b. Install support equipment, environmental control system.
- c. Clean and prime case.
- d. Prepare and process IBT-100 insulation; install in forward and aft domes; cure.
- e. Prepare and process IBT-106 insulation; install in side-wall; cure.
- f. Prepare and process IBT-106 insulation; install forward and aft boots; cure.
- g. Install aft boot extension.
- h. Inspect with NDT.
- i. Remove equipment.

3. Prepare for Casting

- a. Move insulated case to CCT.
- b. Using portable cranes and stiffleg derrick, lift and place case in caisson on thrust ring.
- c. Install environmental shroud, work platforms.

IX.A. Sequence of Operations (cont)

d. Install and assemble core; install centering spider, casting cover, casting stand.

e. Install portable cast building, connect environmental system, start preheat at 135°F (57°C).

4. Process Propellant

a. Grind, blend, and dispense oxidizer.

b. Prepare submix, premix I, premix II; transfer to metering tank or mobile tanker; dispense to mix bowls or transfer to CM hold tanks.

c. Dispense final fuel to carboys or to transfer tank for delivery to CM hold tank.

d. Mix propellant at maximum rate; move mix bowls and transfer pots to Propellant Pot Preparation (PPP) Building at CCT area.

e. Install diaphragm and pressure cover on each pot, move to Cast Building.

5. Cast and Cure Propellant

a. Install casting bayonets.

b. Install propellant pots on cast stand, connect to bayonets, vacuum check.

c. Apply pressure to pots, open pot valve and bayonet valve, cast propellant.

d. Close valves, release pot pressure, return pots to PPP Building for cleaning and recycling.

e. Shorten bayonets.

f. Repeat process steps b. through d. until casting is complete.

g. Remove bayonets, cast stand.

IX.A. Sequence of Operations (cont)

- h. Cure propellant for approximately 28 days at 135°F (57°C).
- i. Reset environmental air to 60°F (16°C), cool propellant for 14 days, minimum.

6. Prepare for Final Assembly

- a. Remove portable Cast Building.
- b. Remove casting cover, core centering spider, casting adapter.
- c. Disassemble and remove core.
- d. Install weather cover on aft end of case; remove shroud adapter, work platforms, shroud, and core support.
- e. Reinstall portable cast building.
- f. Inspect and trim propellant grain.
- g. Process, install, and cure nozzle insulation.

7. Motor Final Assembly and Test Preparation

- a. Assemble TVC system on nozzle, install instrumentation.
- b. Functionally test TVC system.
- c. Remove portable Cast Building.
- d. Remove chamber weather seal and install nozzle/TVC system removal handling fixture.
- e. Install forward mounted igniter (if used) or forward cap, and leak test closure.
- f. Perform motor leak test.
- g. Install flight retention system, side force measurement system.
- h. Remove leak test closure, install exit cone, remove handling fixture.
- i. Install aft end igniter (if used), and weather cover.

IX.A. Sequence of Operations (cont)

8. Static Test

- a. Complete motor instrumentation.
- b. Install quench system.
- c. Install TVC supply and control systems.
- d. Calibrate instrumentation.
- e. Functionally check all test systems.
- f. Operational check on TVC system.
- g. Static test fire.
- h. Operational check on TVC system.
- i. Calibrate instrumentation.
- j. Remove exit cone and nozzle/TVC for inspection
- k. Remove char from insulation and inspect.
- l. Install weather cover over case, store case in caisson.

X. SUMMARY OF RESULTS

Receiving and handling of the full-length motor case would require a dock on Canal C-111, a road from the canal to the CCT facility, and the extension of the stiffleg derrick boom. Estimated cost: \$152,600.

Insulation of the motor case in compliance with the processing plan of Contract NAS3-11224 would require extensive structural and environmental system modifications at the General Processing Building. Estimated cost: \$139,600.

Modifications to the Fuel Preparation Building include operational and dispensing improvements. Estimated cost: \$16,455.

The Oxidizer Preparation Building would be expanded in overall capacity by installing an additional MikroAtomizer system in place of the existing High Speed MikroPulverizer system. Estimated cost: \$128,800.

X. Summary of Results (cont)

The vacuum systems of the vertical batch mixers would be revised to improve deaeration performance. Estimated cost: \$3,500.

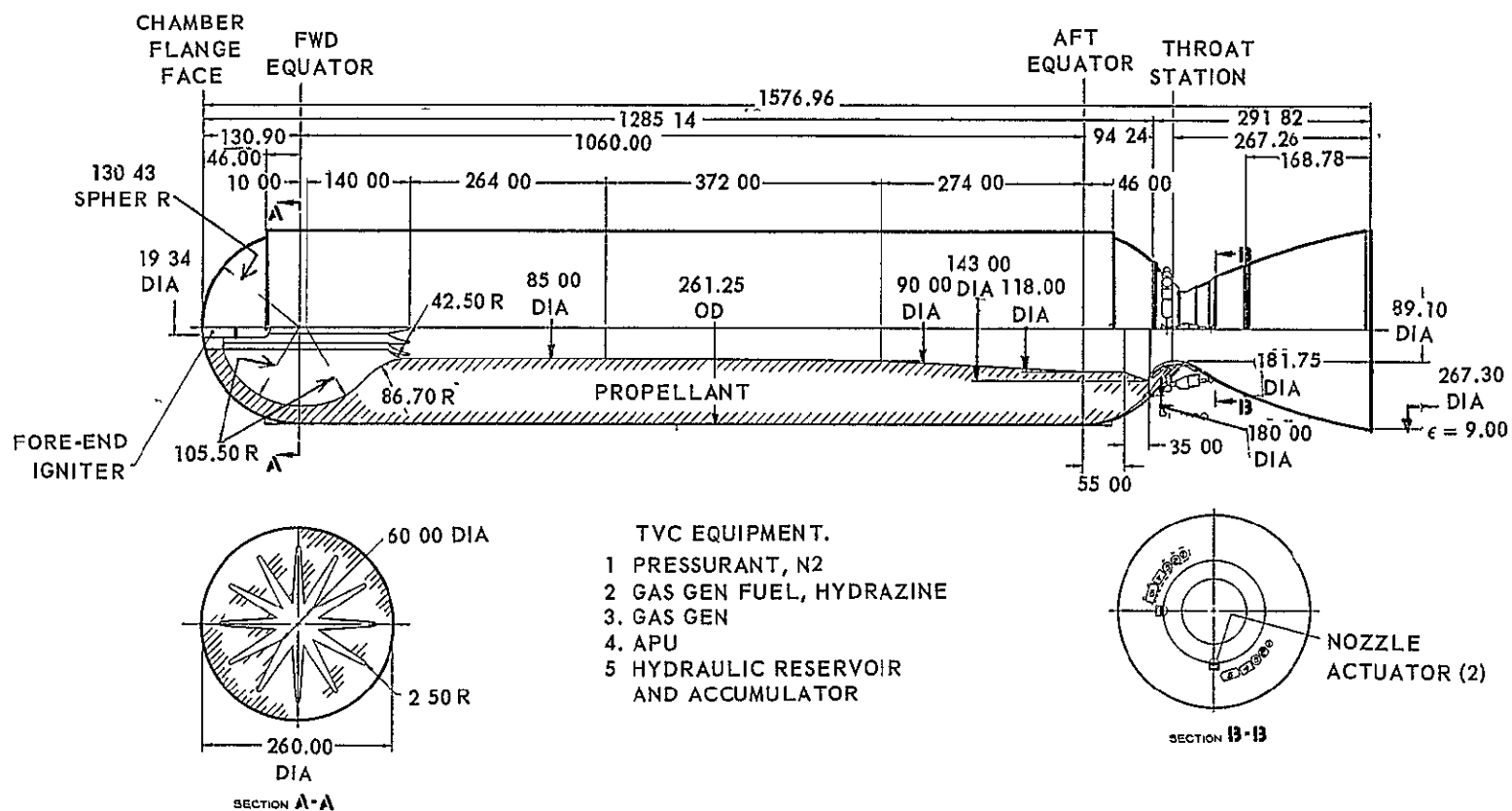
Increased quantities of propellant samples would be accommodated by additional shelving in the QMP curing oven. Estimated cost: \$2,500.

Casting guidelines from Contract NAS3-12002 indicate the necessity for an adjustable, 12-tube bayonet casting system. Other casting-related modifications at the Cast-Cure-Test facility include a new environmental shroud and improved bridge crane capabilities. Estimated cost: \$272,200

Test requirements for a full-length 260-in.(6.6m)-dia motor with a nozzle thrust vector control system would result in a number of modifications and additions to the CCT facility, special test equipment, and instrumentation systems, which vary with the type of TVC system and ignition system mounting location.

Estimated costs:	with movable nozzle TVC, fore-end igniter	\$389,500
	with movable nozzle TVC, aft-end igniter	\$473,600
	with liquid injector TVC, fore-end igniter	\$535,900
	with liquid injector TVC, aft-end igniter	\$620,000

Depending on TVC and igniter options, the total estimated cost of facilities and equipment would range from \$1,105,200 to \$1,335,700.

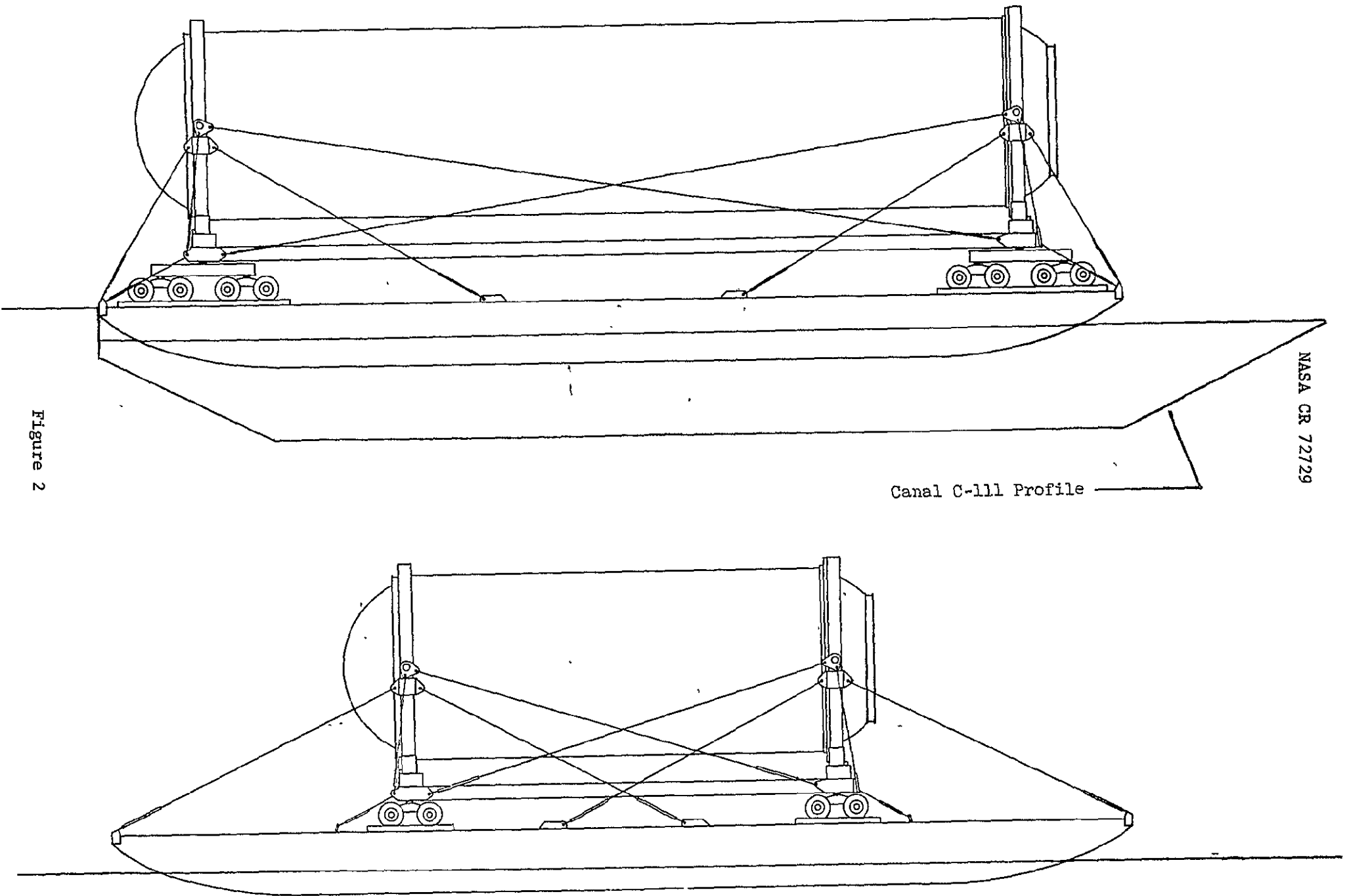


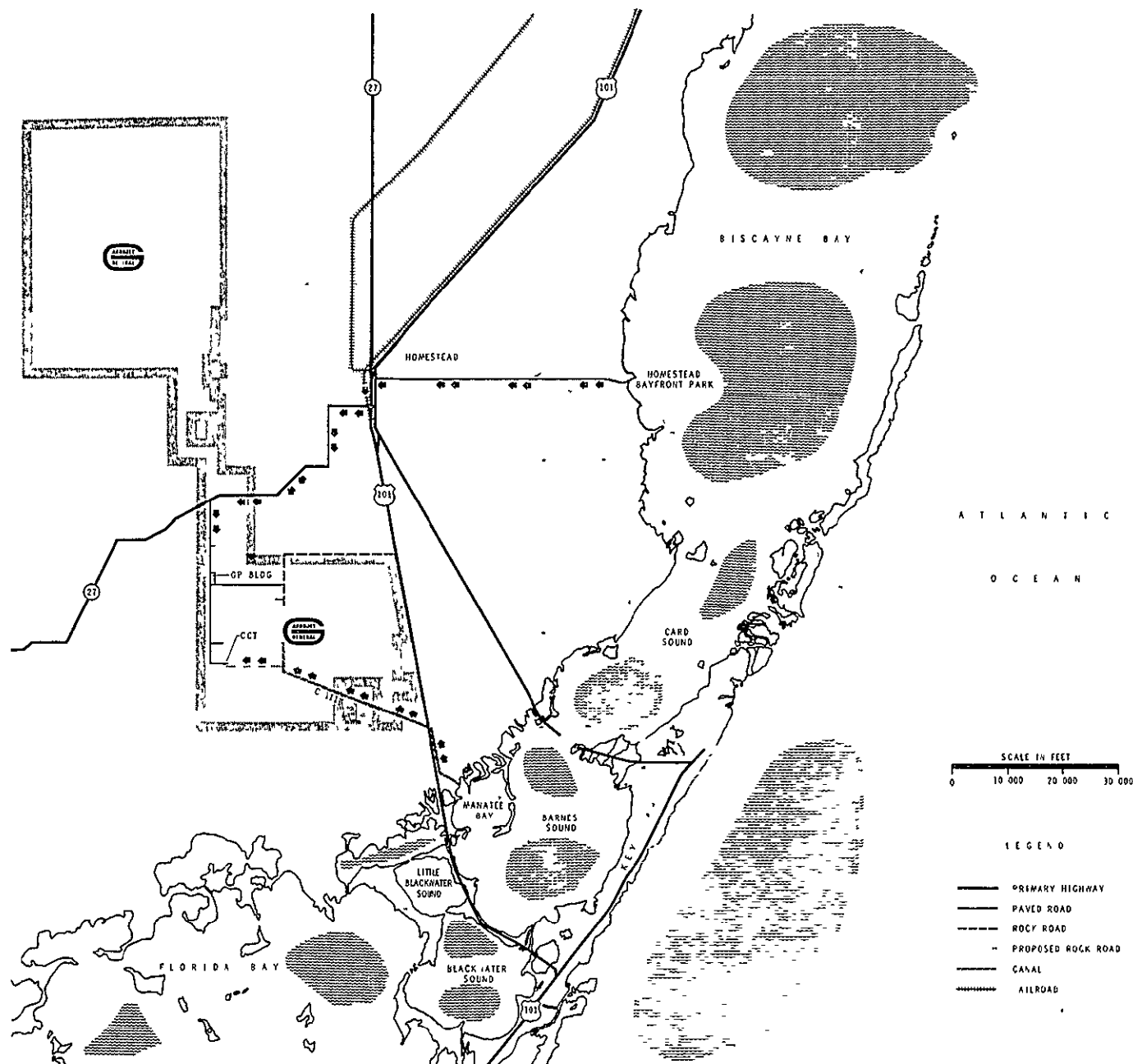
Processing and Test Facilities Requirements, 260-in.-dia Full-Length Motor Assembly

Canal C-111 Profile

Barge and Transporter Arrangement for Short-Length and Full-Length Cases

Figure 2





Map of Case Receiving Routes

Figure 3

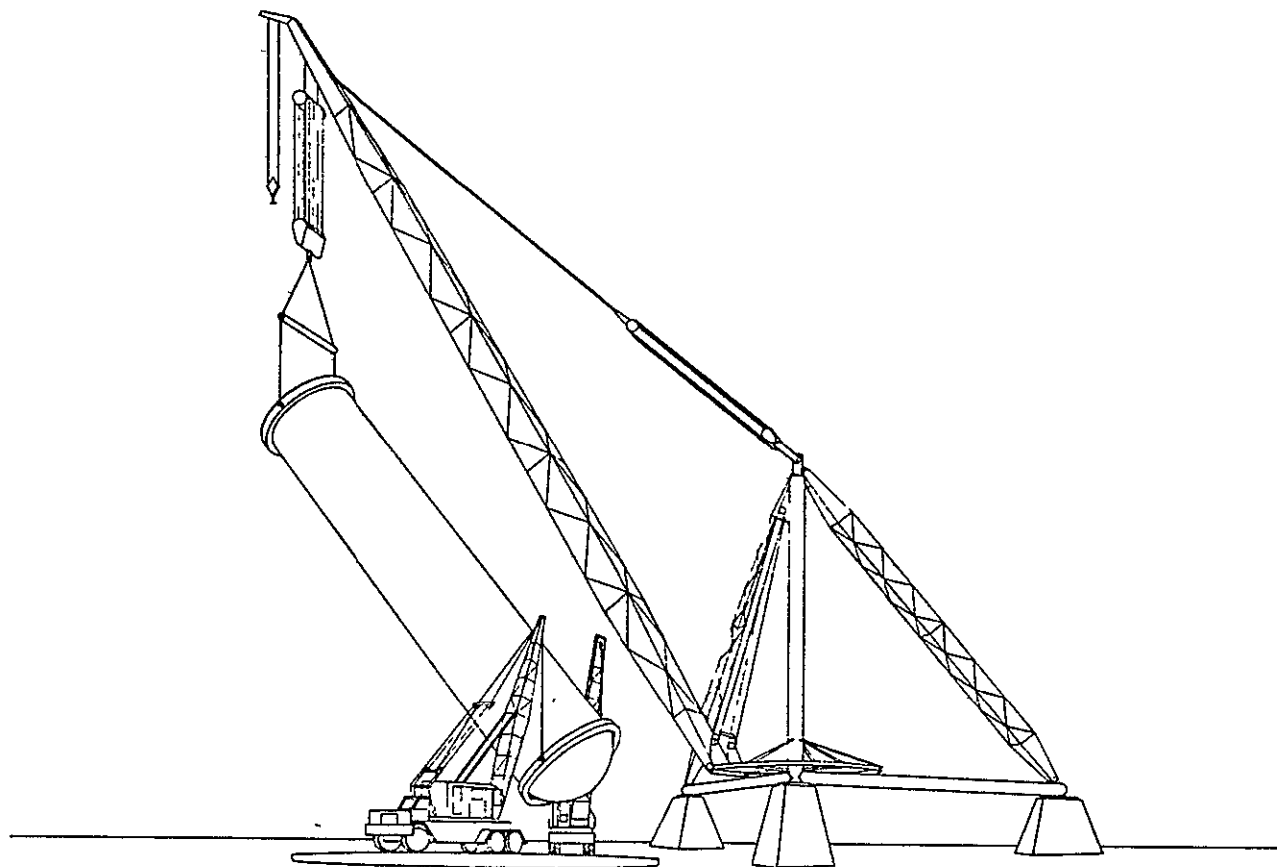
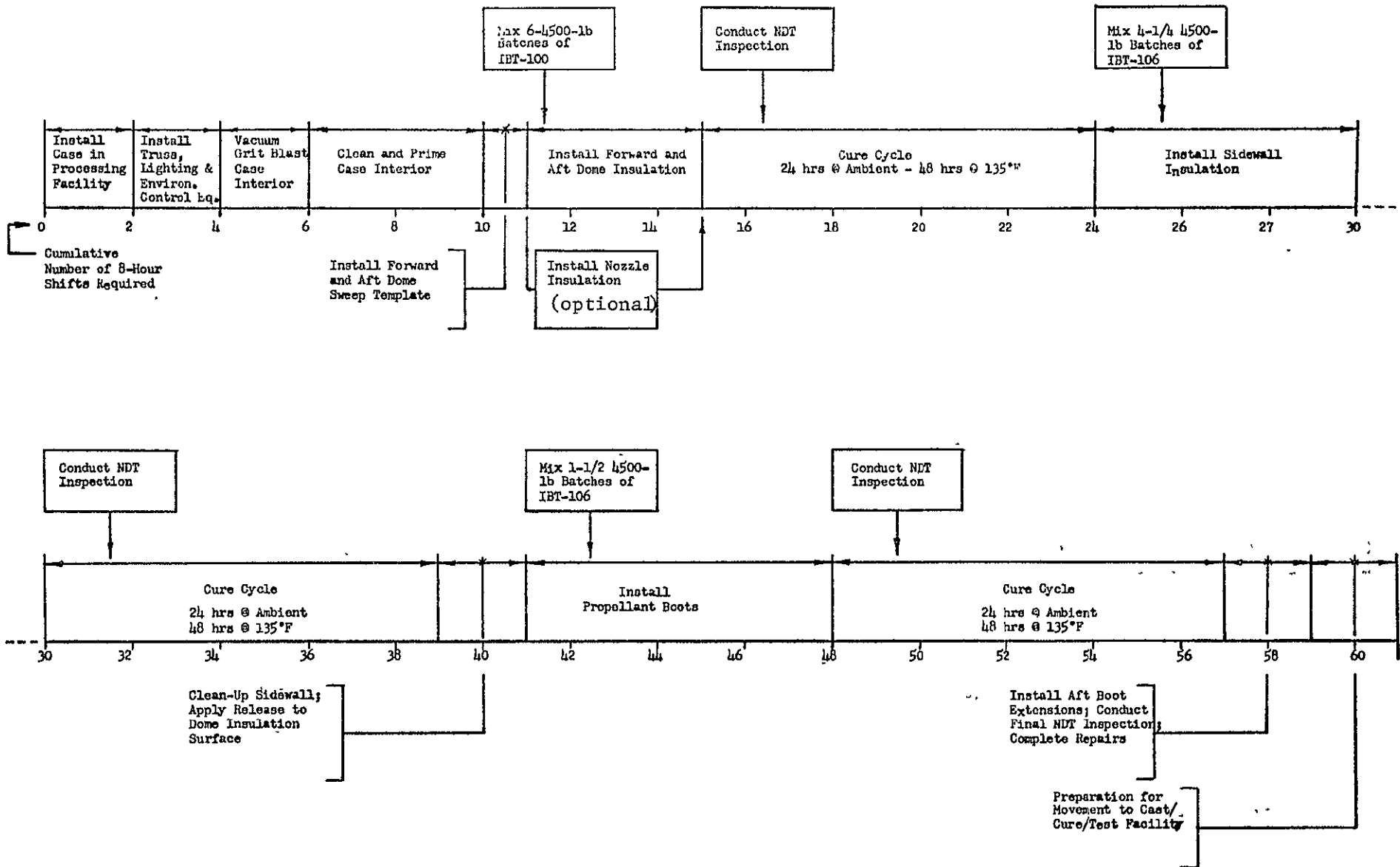


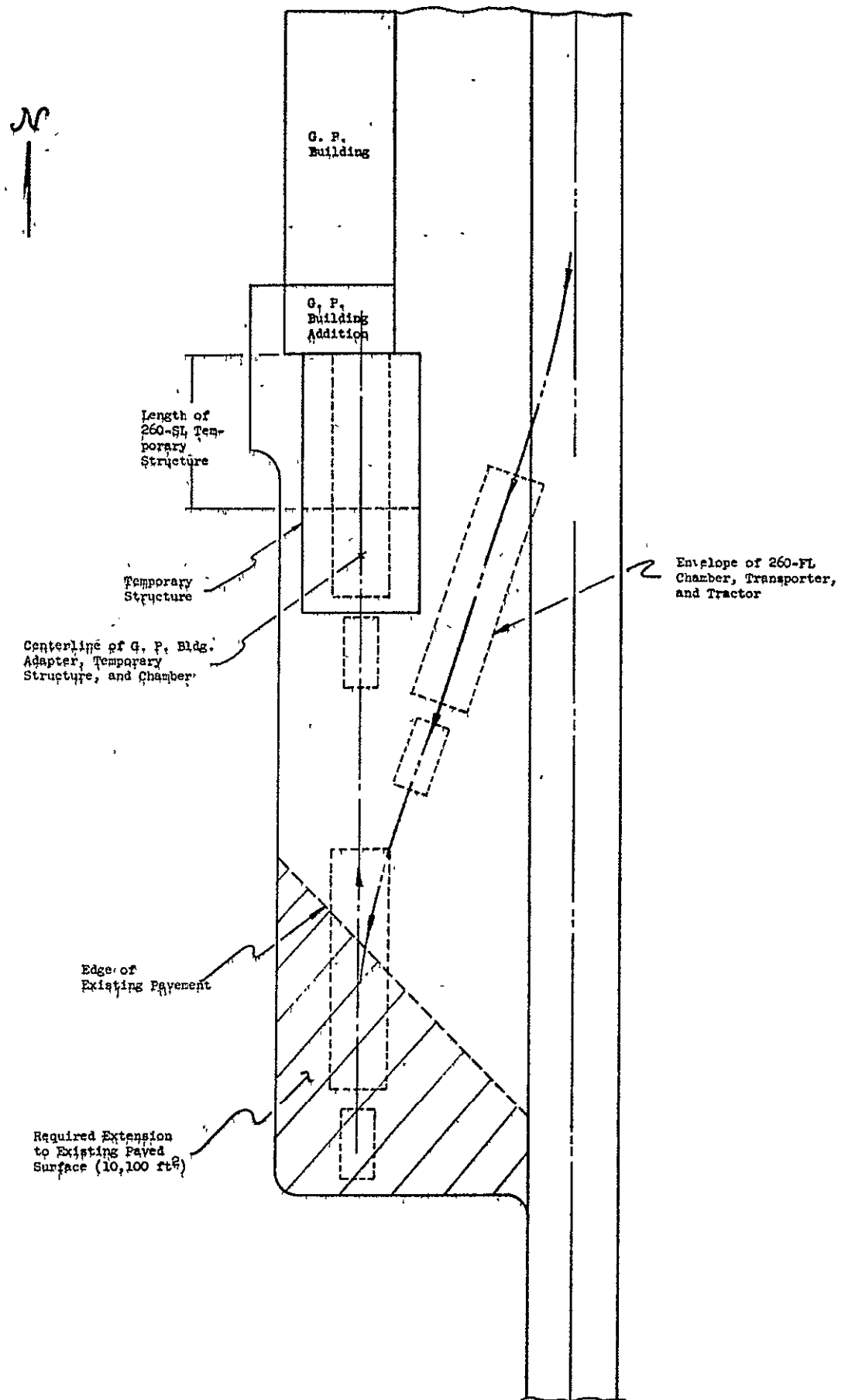
Figure 4

Lifting Full-Length Case at CCT Using Extended Boom Stiff-Leg Derrick



260-FL Motor Insulation System Process Flow Chart

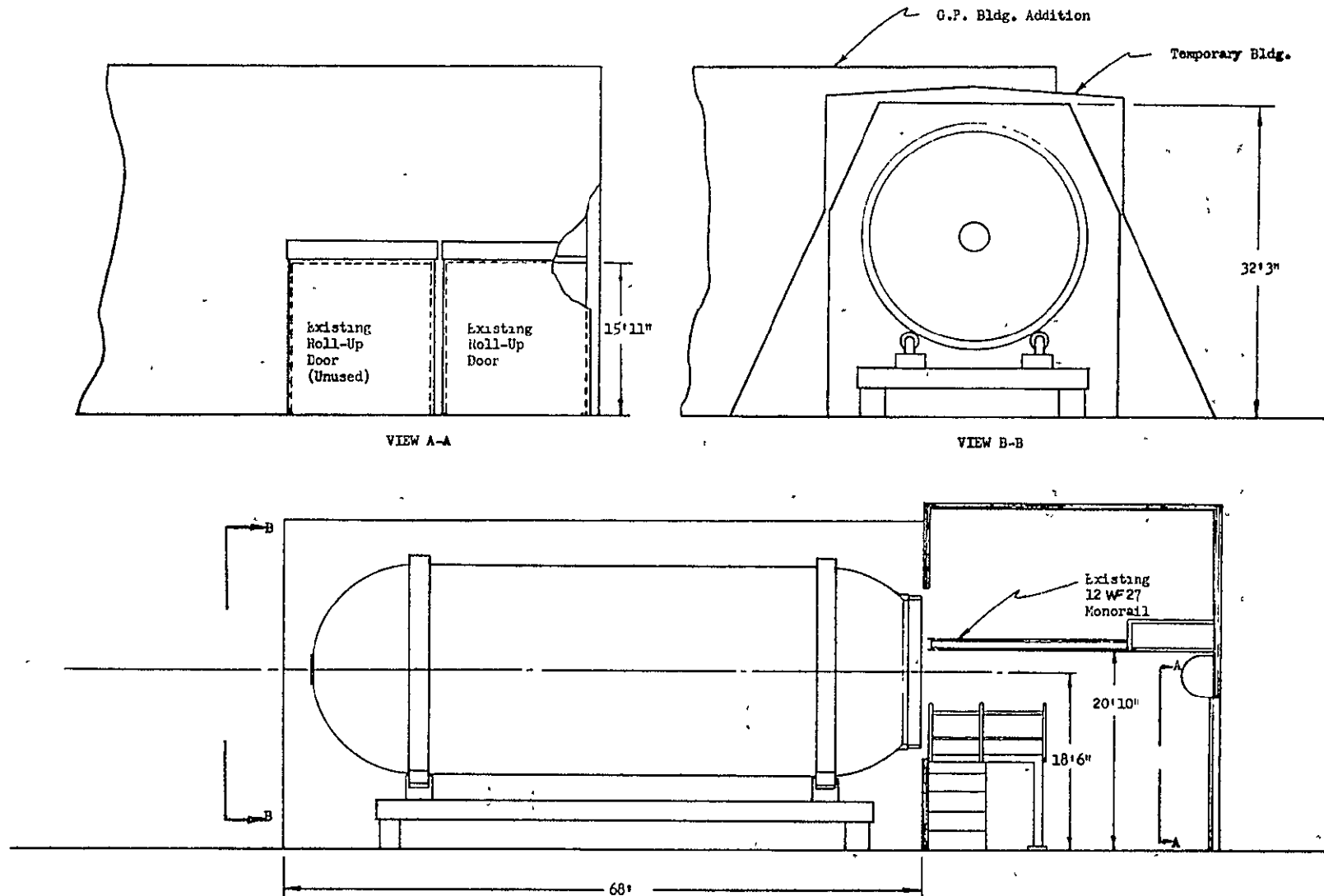
Figure 5



Transporter Maneuvering Area

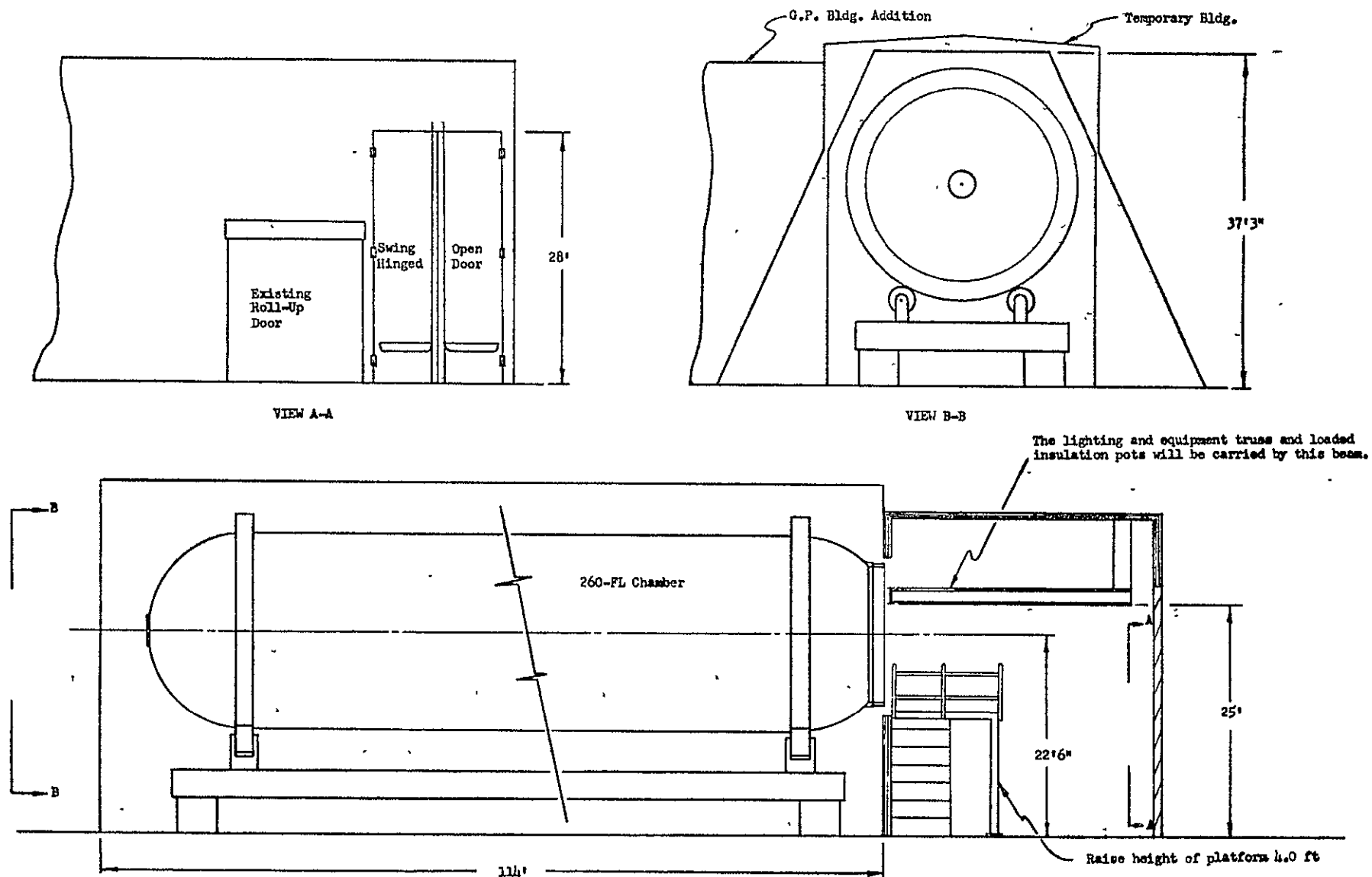
Figure 6

Figure 7.



260-SL Motor Processing Facility

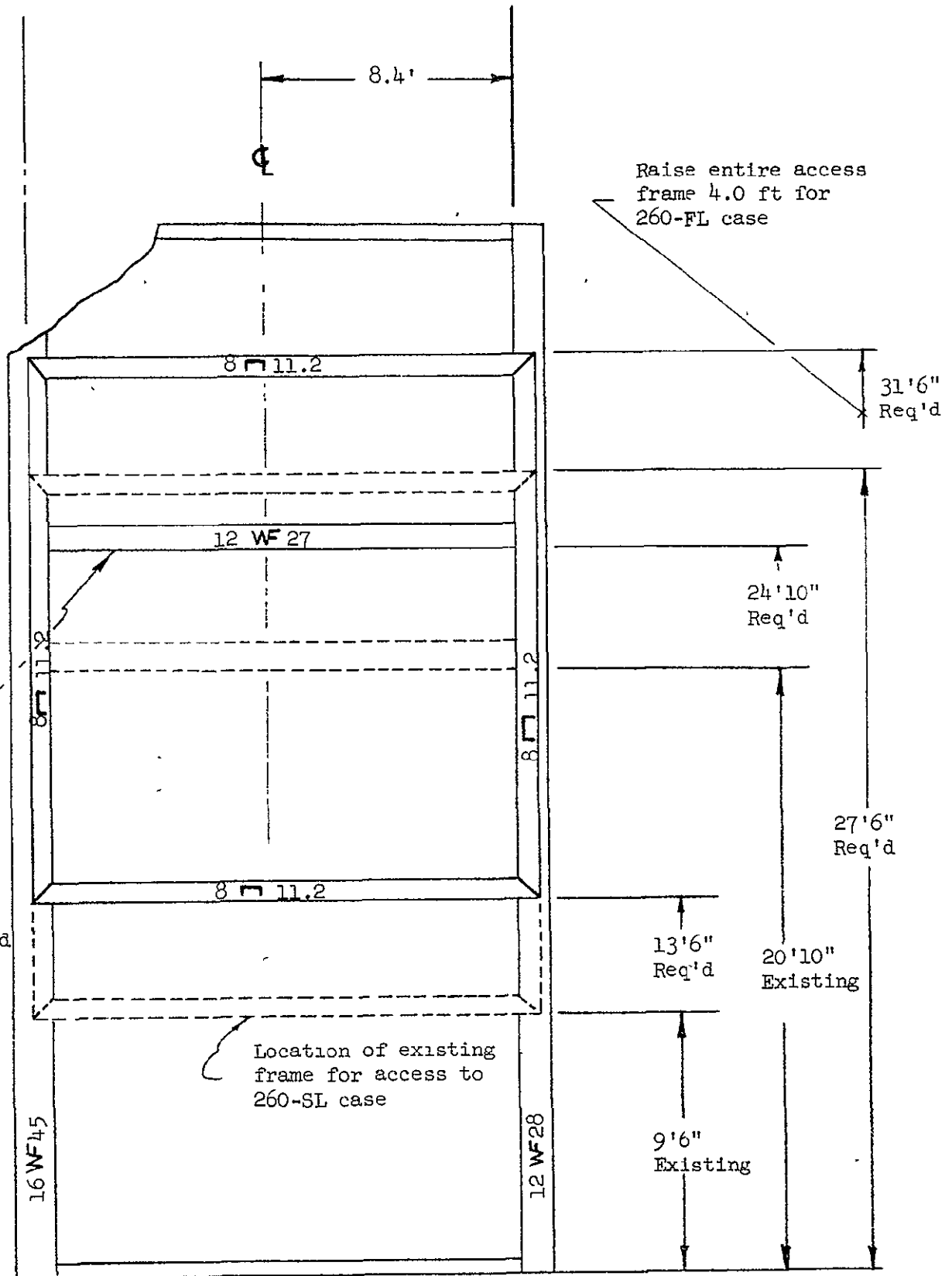
Figure 8



Facility Required for 260-FL Motor Processing

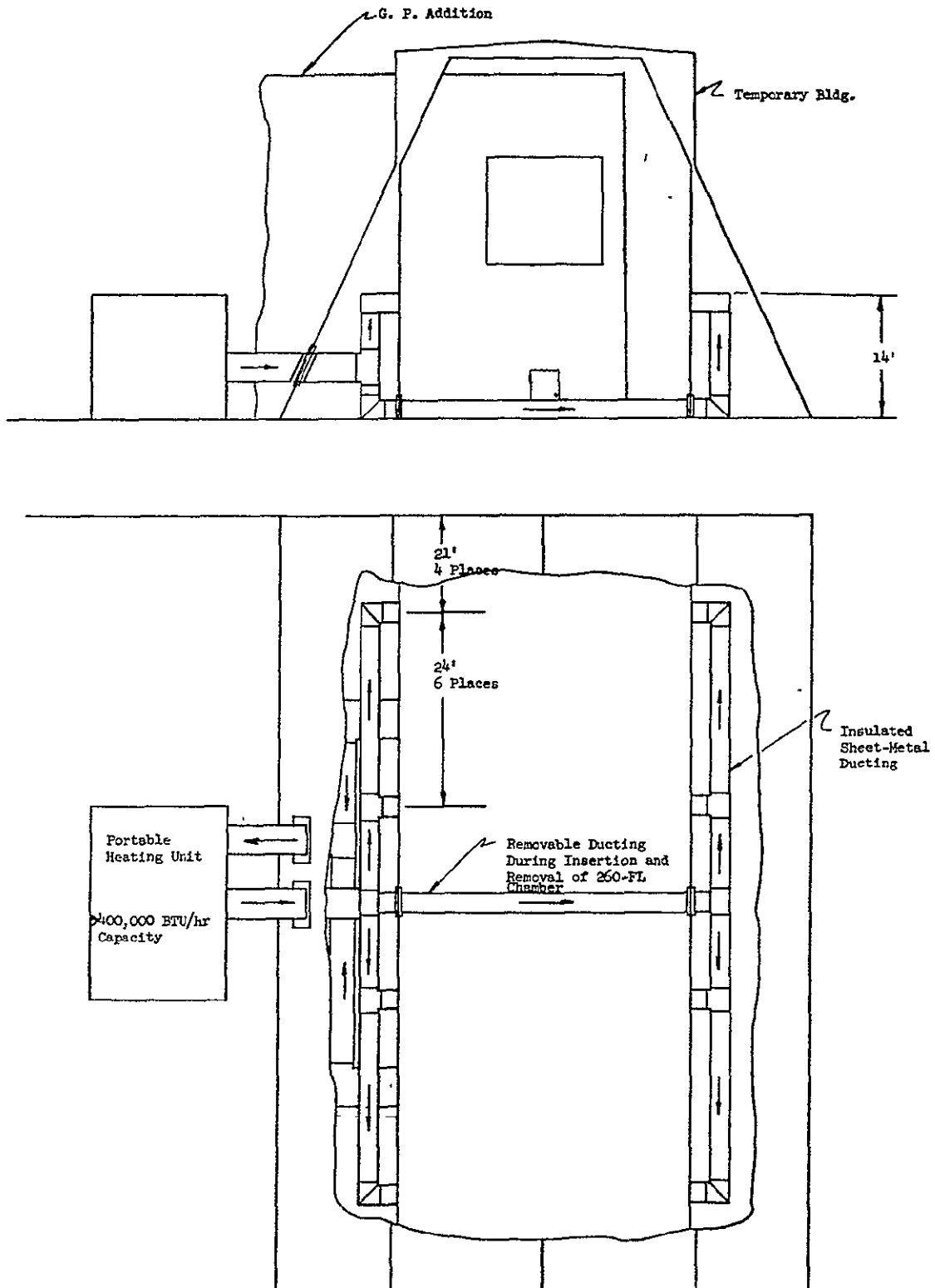
COLUMN C

COLUMN D



General Processing Building Addition, South Elevation, East Corner

Figure 9



Interior Heating and Distribution System for Temporary Building

Figure 10

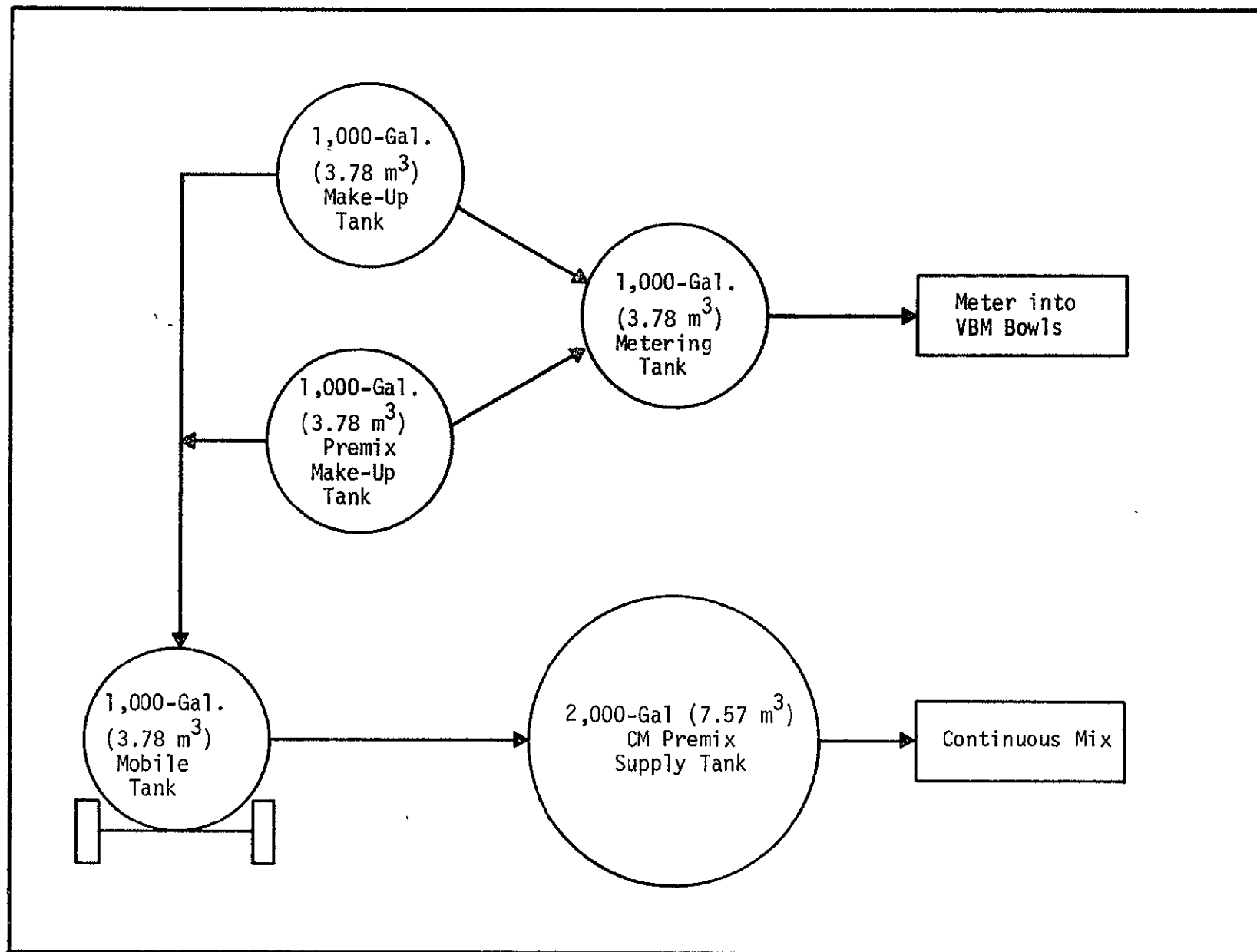
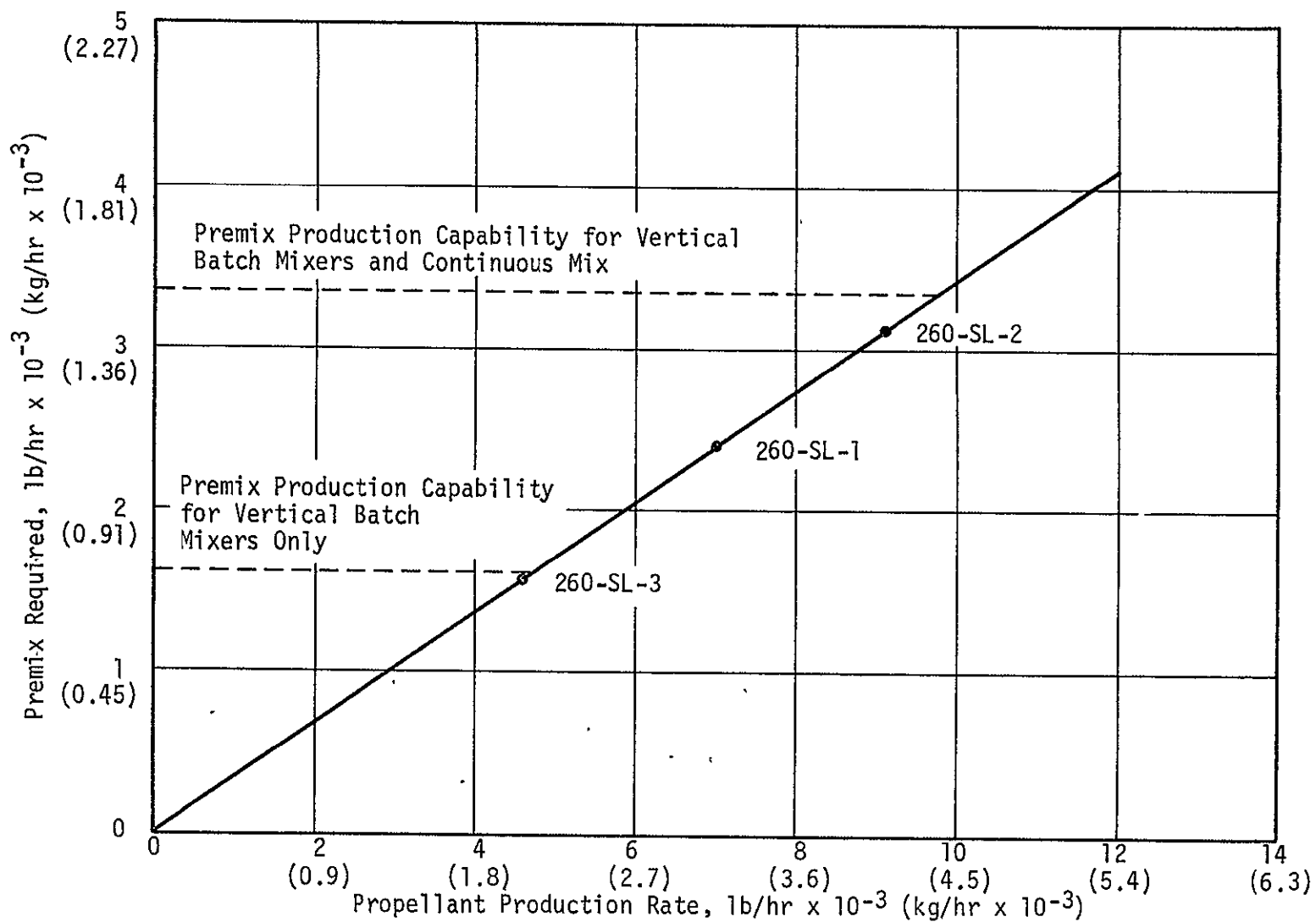


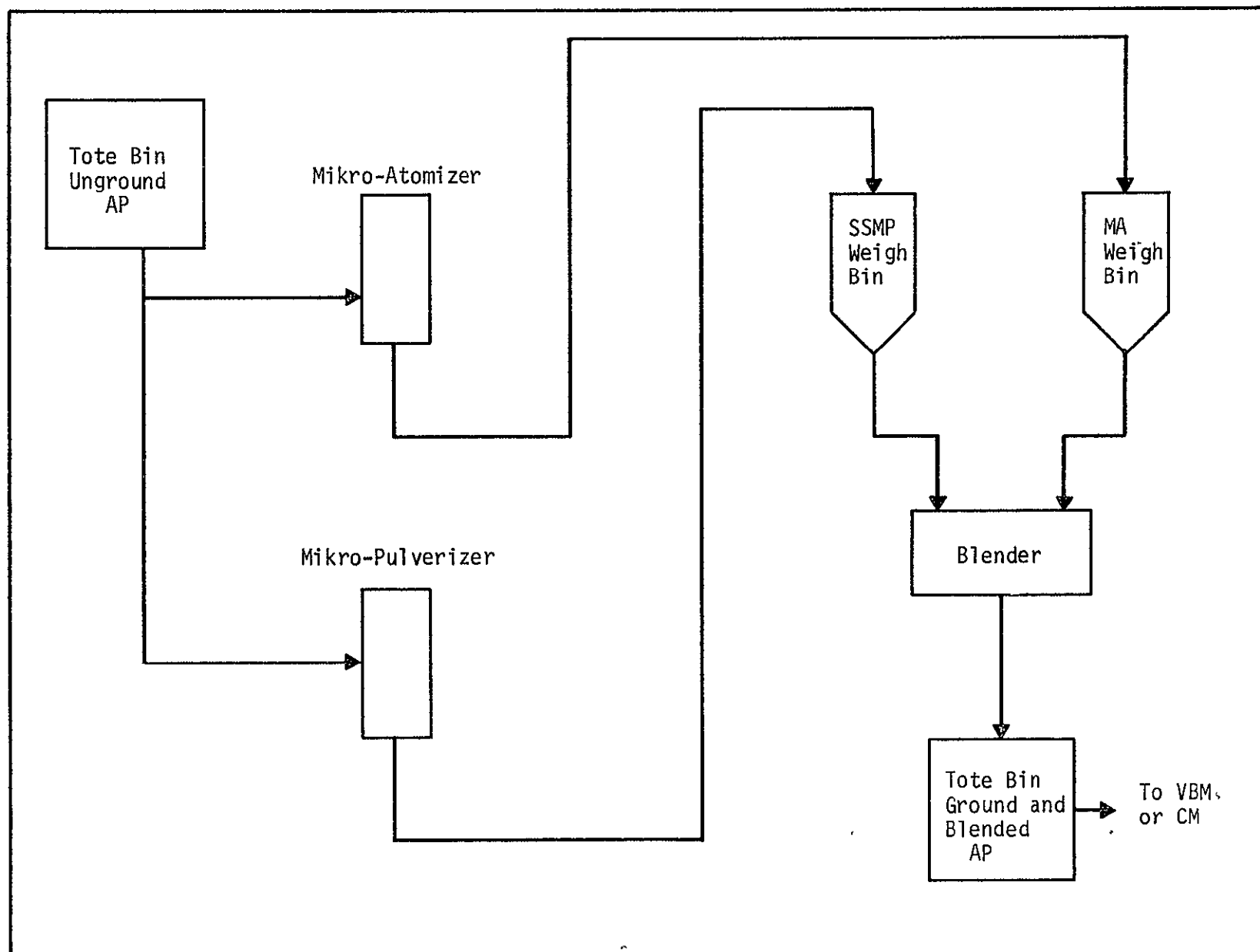
Figure 11

Premix Process Flow Chart

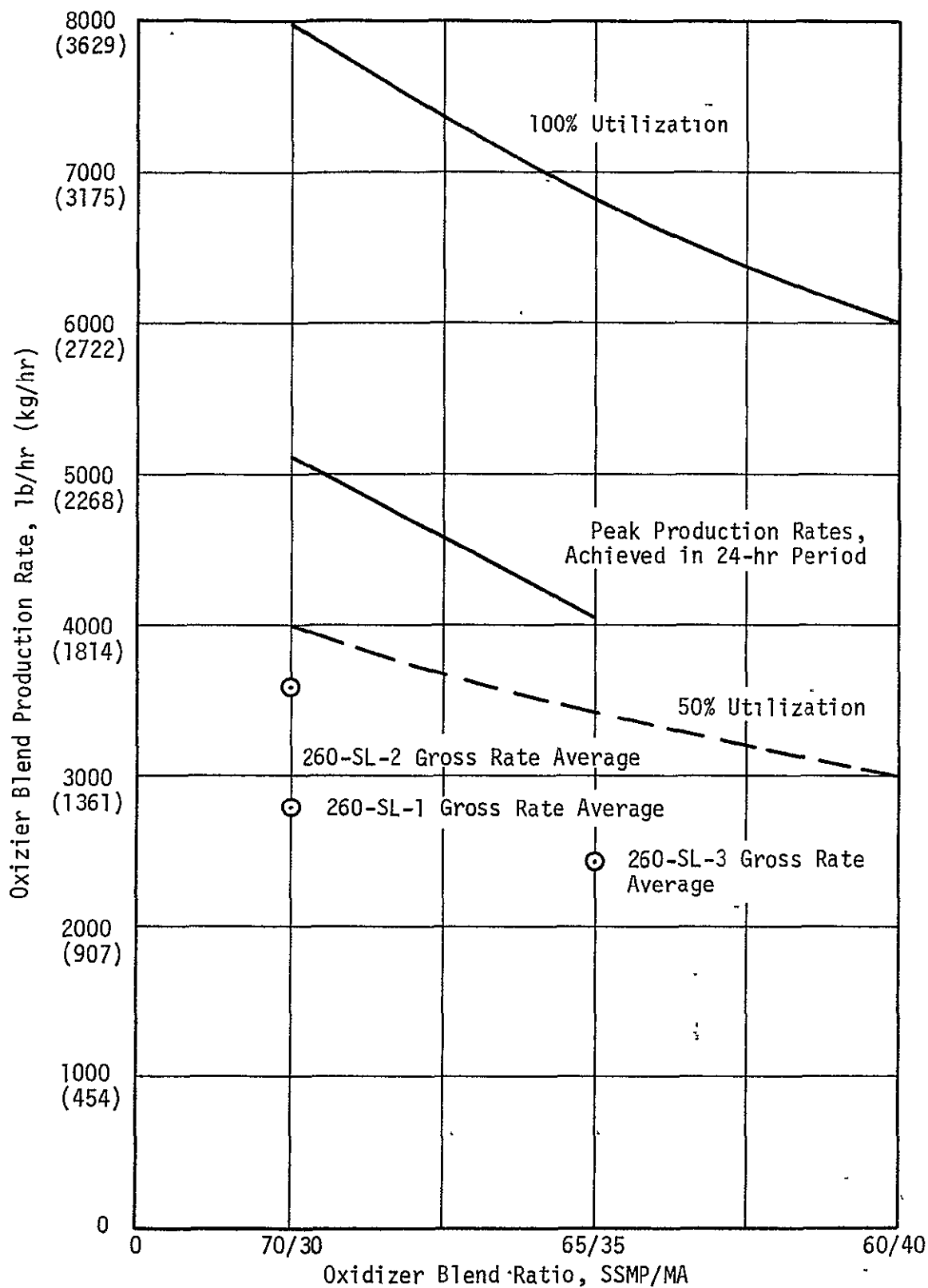
Figure 12



Comparison of Premix Production Capability with Requirements



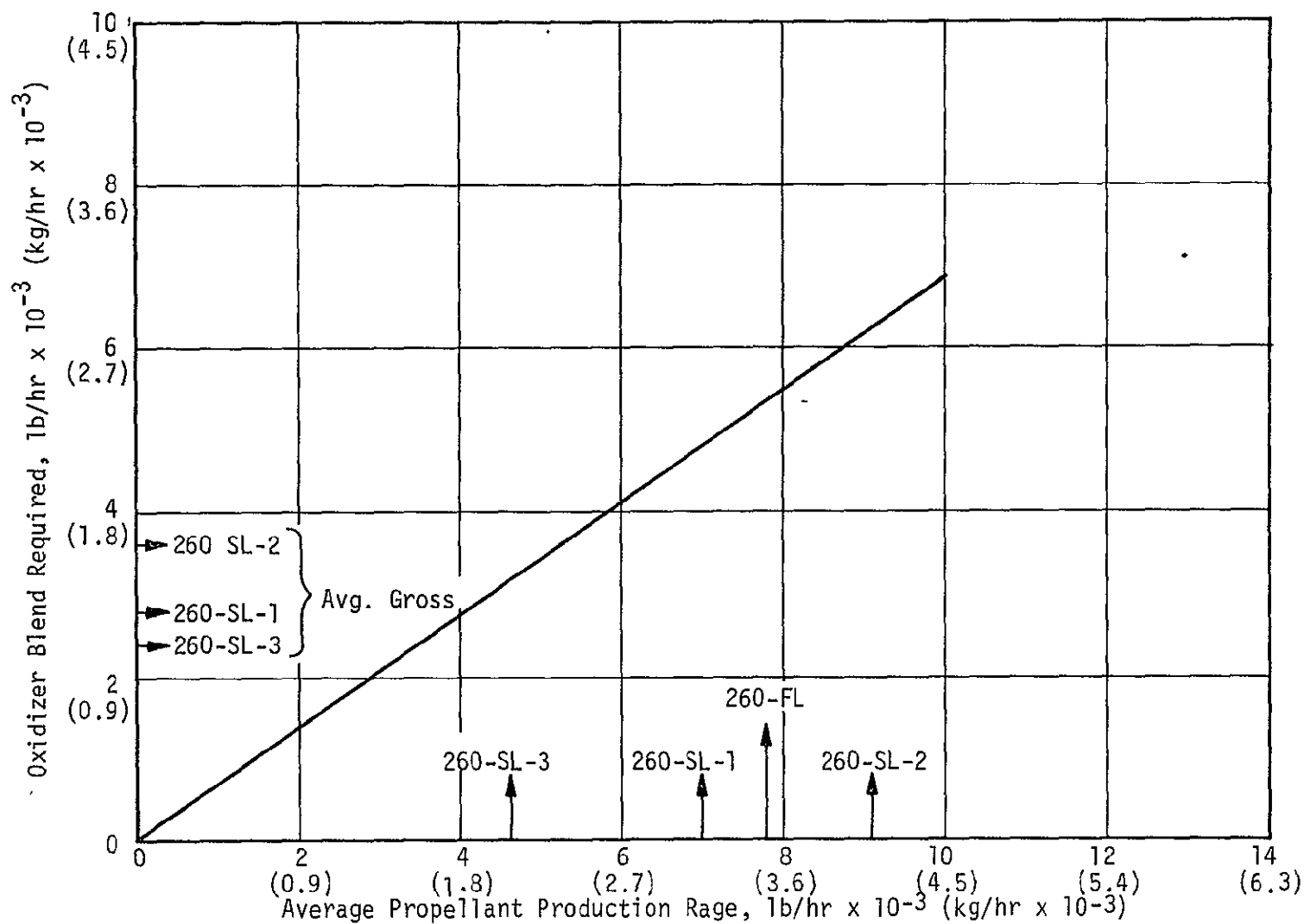
Oxidizer Grinding Process Flow Chart



Oxidizer Blend Production Rates

Figure 14

Figure 15



Oxidizer Blend Production Rate Comparison

<u>Motor</u>	<u>Two Vertical Batch Mixers</u>	<u>Continuous Mixer</u>	<u>Total</u>
260-SL-1	4046 (1835)	2974 (1337)	6993 (3172)
260-SL-2	5790 (2626)	3318 (1505)	9108 (4131)
260-SL-3	4512 (2047)	--	4512 (2047)

Average Propellant Production Rates, lb/hr (kg/hr)

Figure 16

<u>Oxidizer Blend Ratio, SSMP/MA</u>	<u>Propellant Production Rate, lb/hr (Kg/hr)</u>	<u>Time Required*** to Produce Oxidizer, hr</u>	<u>Time Required to Process 3,400,000 lb (1,540,000 Kg) Propellant, hr</u>	<u>Quantity of Preground Oxidizer Required, lb (Kg)</u>	<u>Maximum Oxidizer Blend Storage Time Required, hr</u>
70/30	7795* (3536)	620	436	736,000 (334,000)	184
70/30	4477** (2031)	620	759	0	0
65/35	7795 (3536)	728	436	996,000 (452,000)	292
65/35	4477 (2031)	728	759	0	0

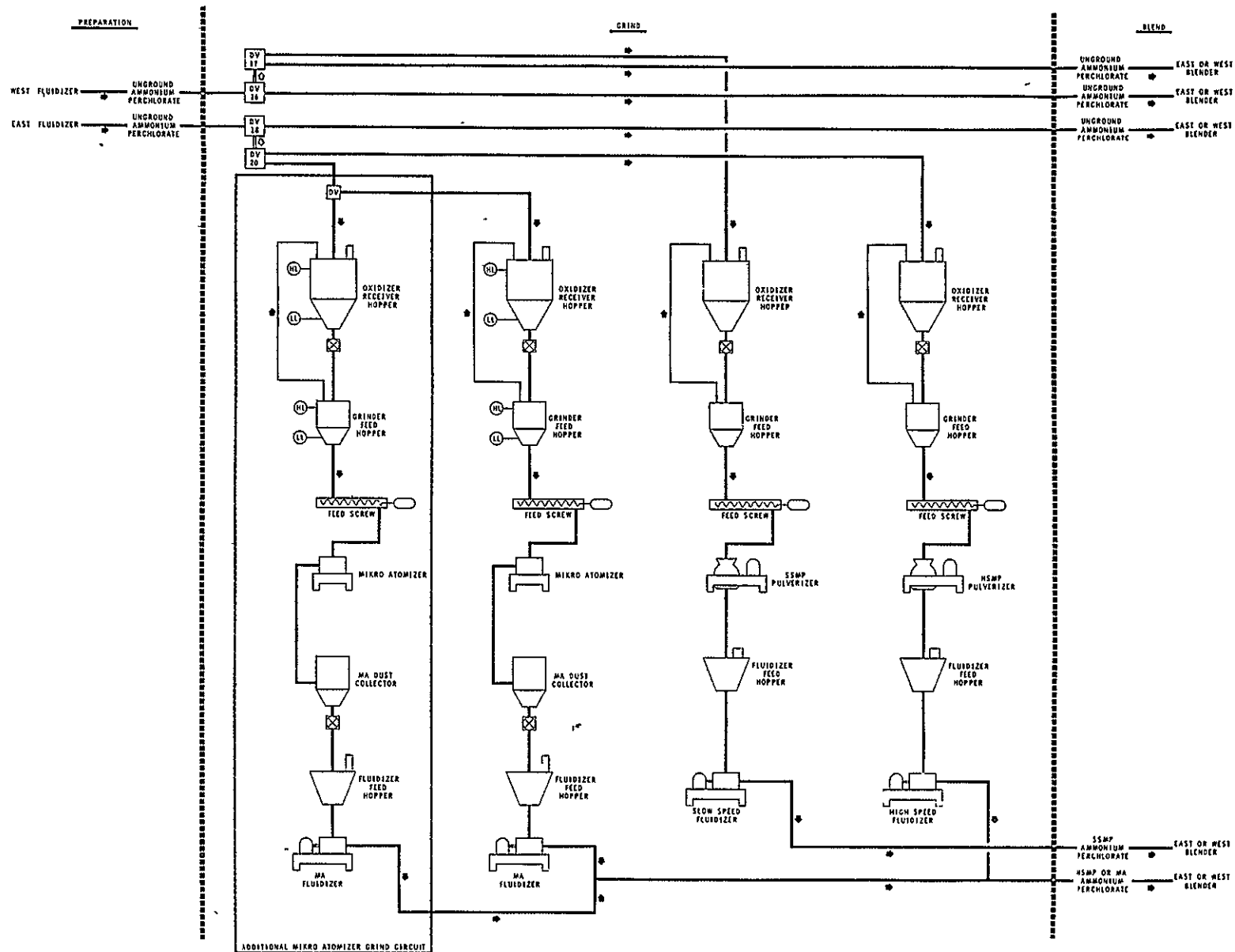
* Sum of 260-SL-2 average production rate for continuous mix and estimated rate for two vertical batch mixers with revised mix cycle.

** Estimated rate for two vertical batch mixers with revised mix cycle.

***Assuming 50% utilization of grind capacity and 2,480,000 lb (1,125,000 Kg) of oxidizer required (95% utilization of product).

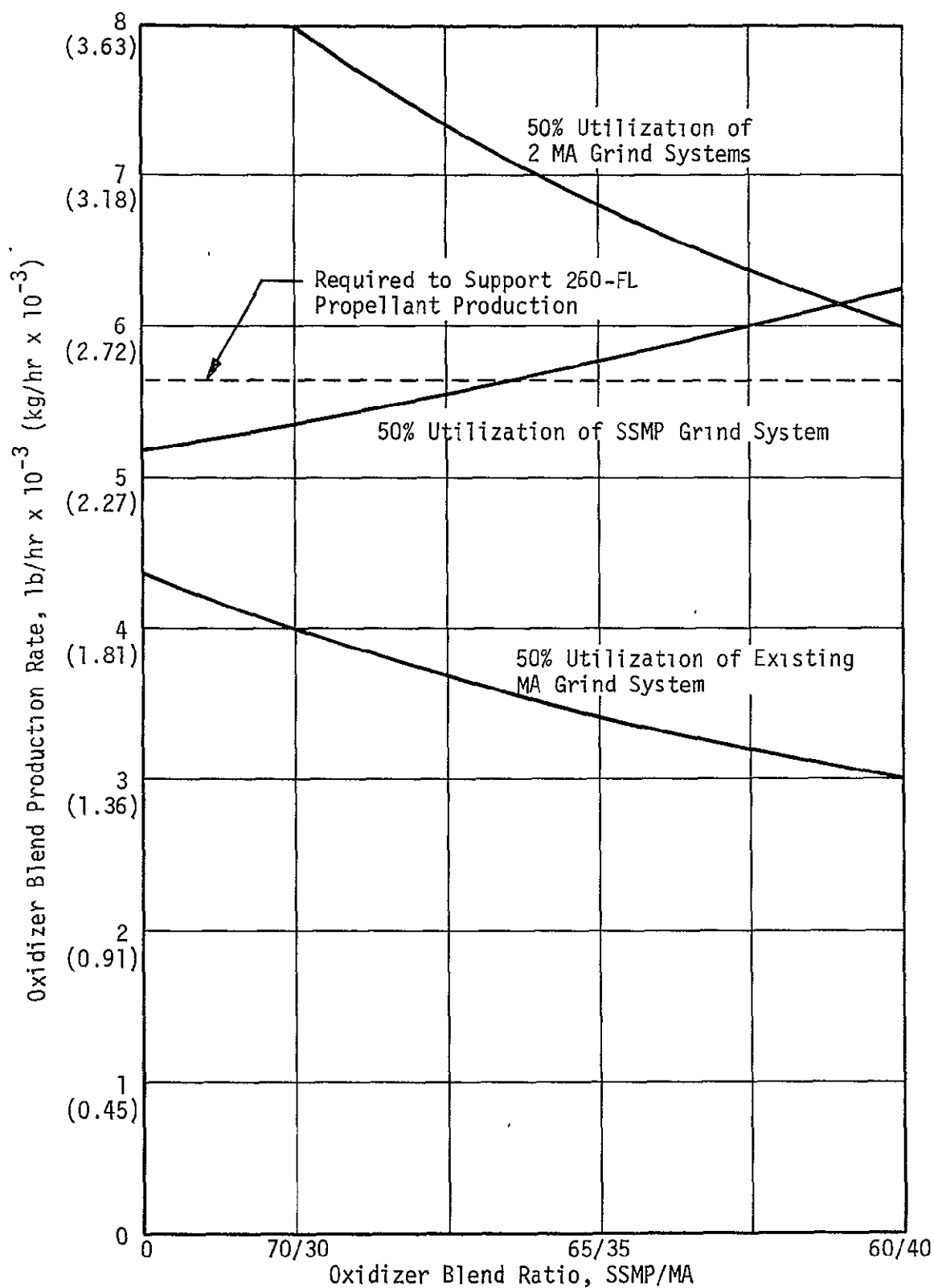
Effect of Propellant Production Rate
on Oxidizer Production Time and
Pregrinding Requirements

Figure 18



NASA CR 72729

Diagram Showing Additional MA Grind Circuit



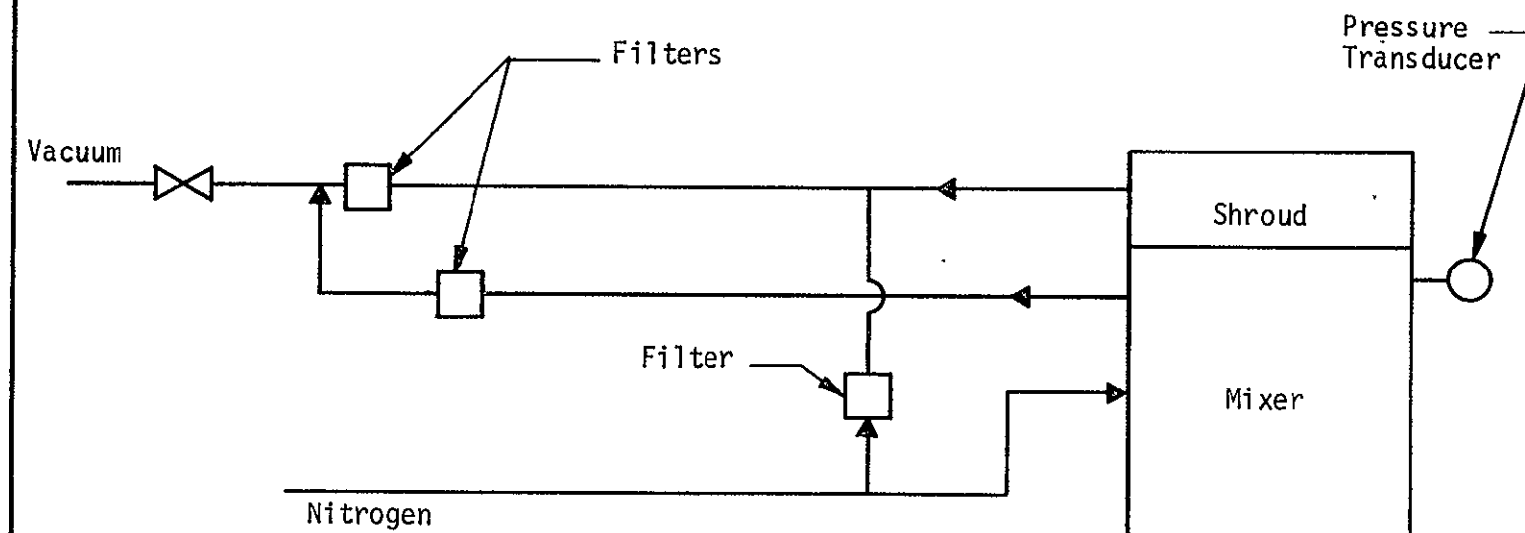
Oxidizer Blend Production Rate Limits

Figure 19

	Time, minutes		
	<u>SL-1</u>	<u>SL-2</u>	<u>SL-3</u>
Batch Start to Bowl-Up	58.5	37.3	42.0
Bowl-Up to Bowl-Down	85.5	87.5	102.0
Bowl-Down to Finish	15.5	9.7	14.0
Mix Cycle	159.5	134.5	158.0
Interval Between Batches	2.6	-18.5	-11.0
Total Batch Cycle	162.1	116.0	147.0

Cycle Times for Vertical Batch Mixers

Figure 21



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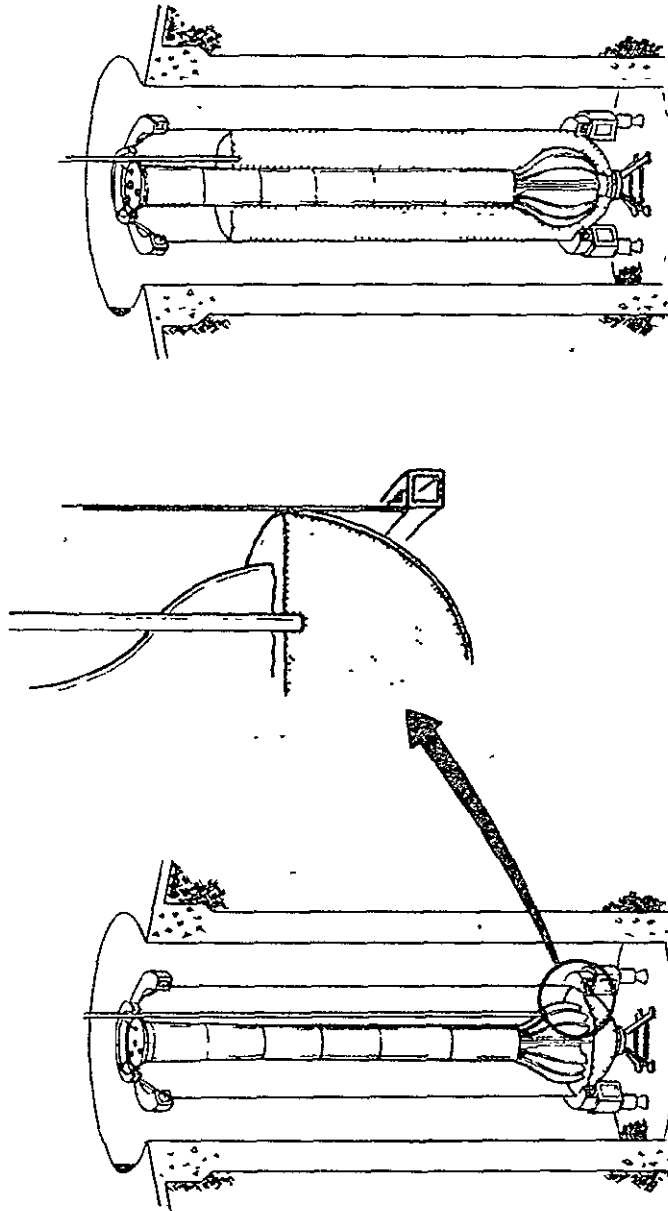
Diagram of Revised Vacuum and Nitrogen Systems of Vertical Batch Mixers

AP	511 tote bins
Al	925 55-gal (0.21 M ³) drums
Fe ₂ O ₃ *	1480 50-lb (23 kg) bags
Iron Blue*	74 50-lb (23 kg) bags
L-45	185 lbs (84 kg)
FC-151	27 5-gal (0.019 M ³) cans
PBNA*	74 50-lb (23 kg) bags
FC-167*	61 50-lb (23 kg) bags
PBAN	45,435 gal (172 M ³)
DOA	16,535 gal (62.5 M ³)
DER-332	93 55-gal (0.21 M ³) drums
LD-124	9 55-gal (0.21 M ³) drums
MNA	17 55-gal (0.21 M ³) drums
Sb ₂ O ₃ *	146 50-lb (23 kg) bags
P-33*	93 50-lb (23 kg) bags
Shawinigan Black*	24 30-gal (0.11 M ³) fiberpacks
7TF-1 Asbestos*	112 50-lb (23 kg) bags
7DO-4 Asbestos*	60 50-lb (23 kg) bags
FeAA	2 55-gal (0.21 M ³) drums

*Total of 2124 50-lb (23 kg) bags that must be stored in RH controlled environment or repackaged in approximately 200 55-gal (0.21 M³) drums.

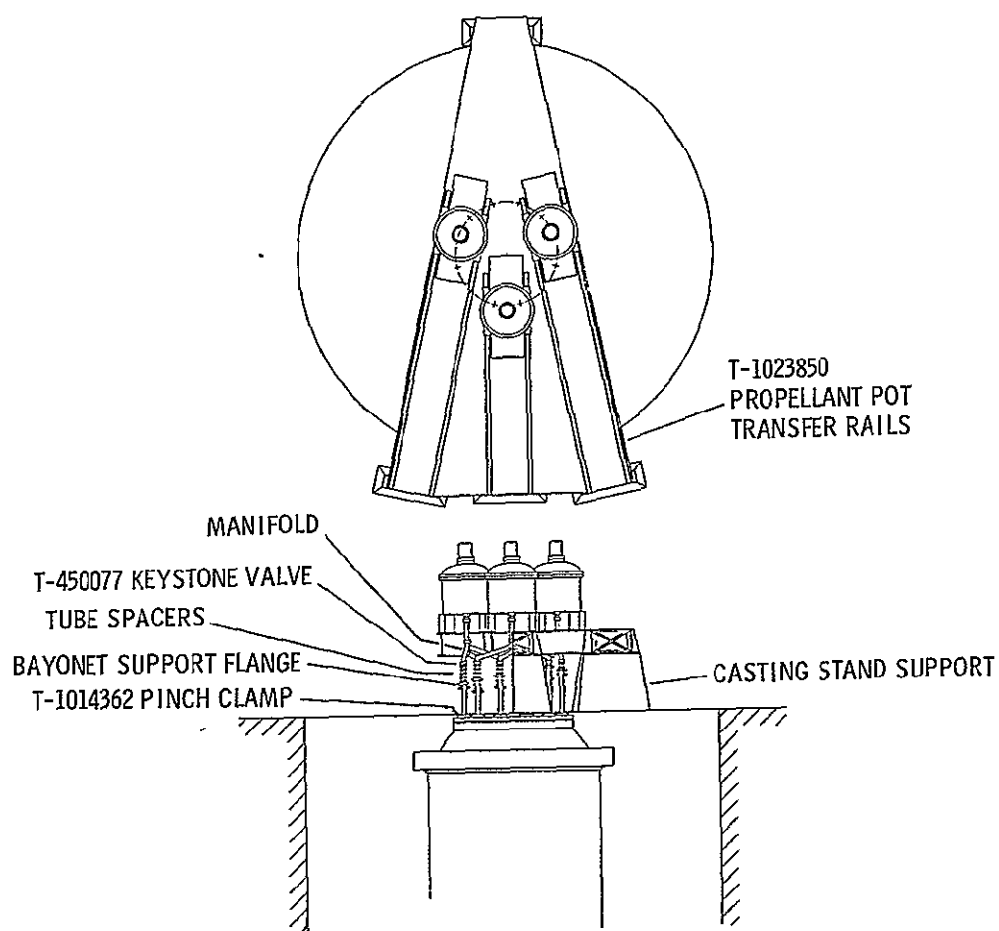
Total Propellant and Insulation Materials Requirements

Figure 22



Propellant Casting

Figure 23



Processing and Test Facilities Requirements, Adjustable 12-Bayonet Casting Concept

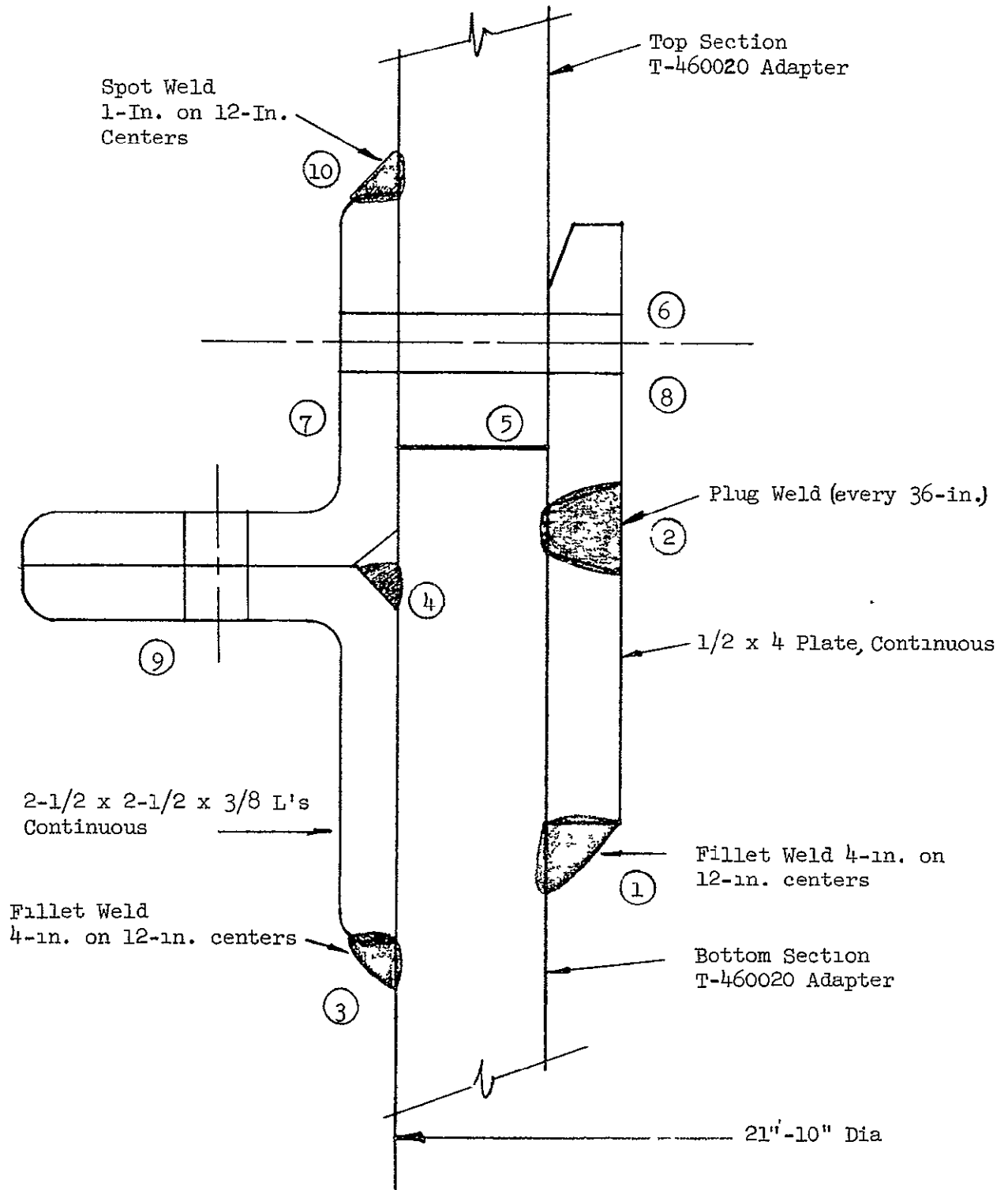
Figure 24

Parameters	Qty.	Visual	Brown	O'graph	ADC	DC Amps	HF Tape	Notes
Motor P _C	3		2	3	3	3		
Igniter P _C	2			2		2		
Fy	6			6	6	6		
Fx	6			4	4	4		
Fz	4			6	6	6		
TVC Positions	8	4		8	8	-		
TVC Commands	2			2	2	2		
Miscellaneous Pressure	6			6	6	6		
Temperature, Continuous	20			5	15			
Thermocouples, Samples (30/3)	3			3				Commutated 10:1 Three groups of 10
Acceleration	12						12	
Voice, Time	2			1			2	
Facility Pressures	15	4		15		4		
Strain Gages	20			20				
Miscellaneous Positions	7	1		7				
Voltage, Current	12			12				
Events	14			14				
Totals	142	9	2	114	50	33	14	

Instrumentation Listing - Flexseal Option

Parameters	Qty.	Visual	Brown	O'graph	ADC	DC Amps	HF Tape	Notes
Motor P _c	3		2	3	3	3		
Igniter P _c	2			2		2		
Fy	6			6	6	6		
Fx	4			4	4	4		
Fz	6			6	6	6		
TVC Positions	8	4		8	8			
TVC Commands	2			2	2	2		
Miscellaneous Pressure	6			6	6	6		
Temperature Continuous	20			5	15			
Thermocouples, Sampled (40/4)	40/4			4				Commutated 10:1, 4 groups of 10
Acceleration	12						12	
Voice, Time	2			1			2	
Facility Pressures	15	4		15		4		
Strain Gages	20			20				
Miscellaneous Positions	23	1		23				
Voltage, Current	12			12				
Events	14			14				
Totals	159	9	2	131	50	33	14	

Instrumentation Listing - LITVC Option

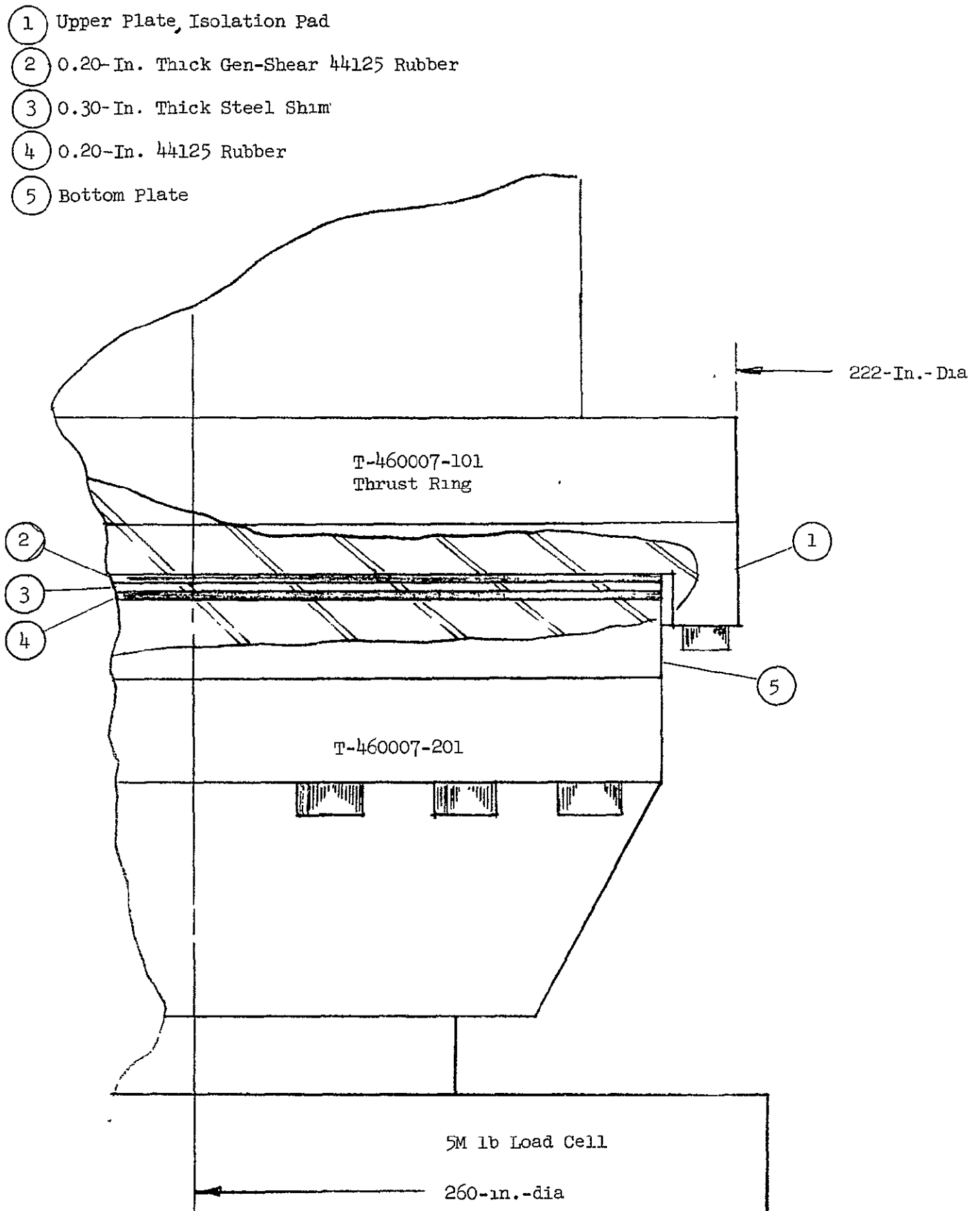


T-460020 Thrust Adapter Modification
Field Reassembly Joint

ASSEMBLY SEQUENCE

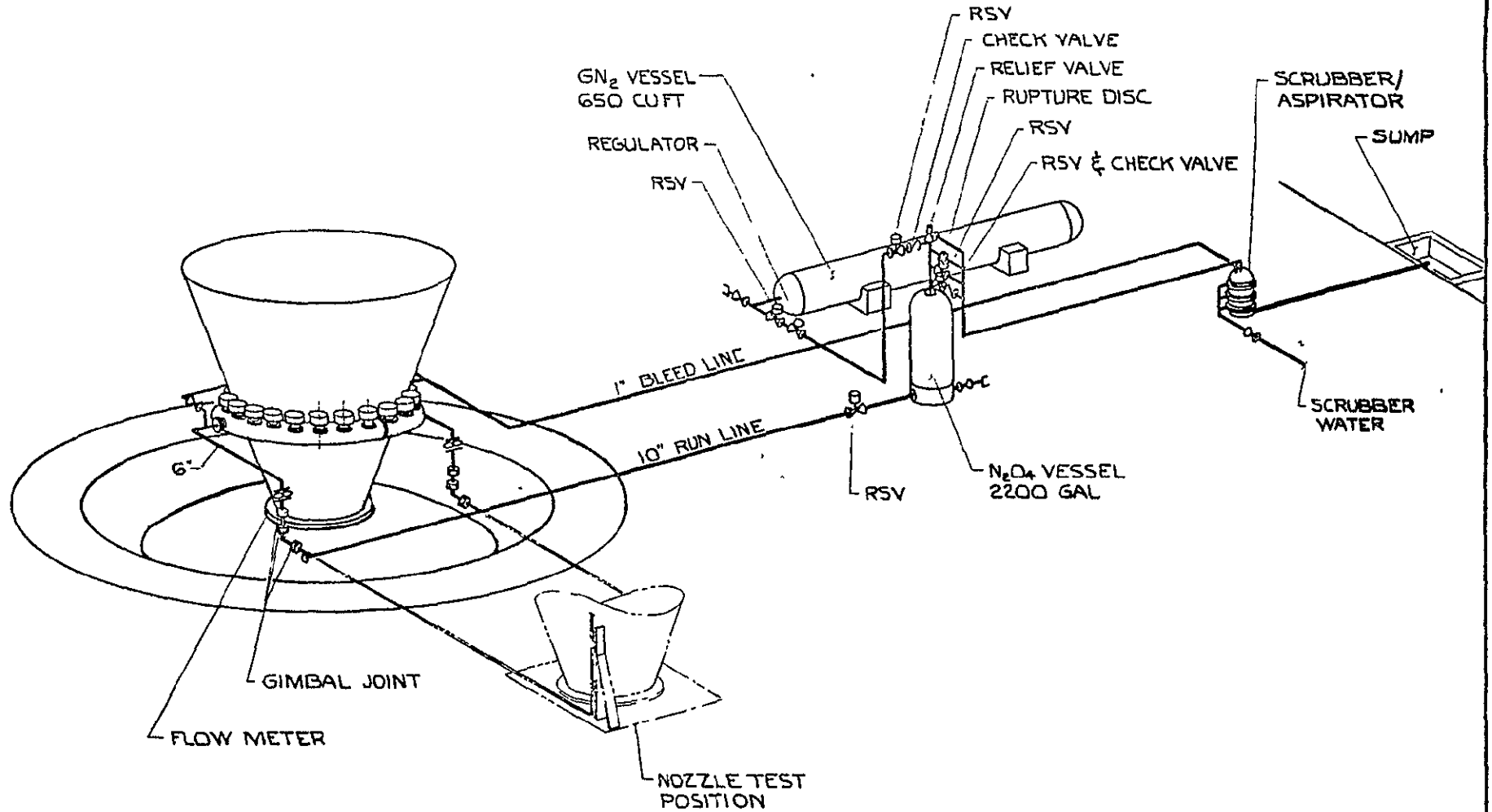
- (1) (2) Weld back-up plate to inside diameter of lower adapter section.
- (3) (4) Locate and weld outside support angle to lower adapter section.
- (5) Mate upper and lower adapter sections; soft metal shims may be used if necessary to assure 100% contact at joint interface.
- (6) Locate and drill bolt holes; 9/16-in.-dia on 36-in. centers.
- (7) Position upper retaining angle so as to be resting on lower angle. Locate bolt holes from inside for field fit and drill holes.
- (8) (9) Install and torque bolts.
- (10) Optional weld; would be made only after loaded motor weight applied to adapter.

T-460020 Thrust Adapter Modification
Field Reassembly Joint



Axial Load Cell Isolation Assembly, Rubber/Steel Laminated Pad

Figure 29



Ground Support Liquid Injection Supply and Distribution System

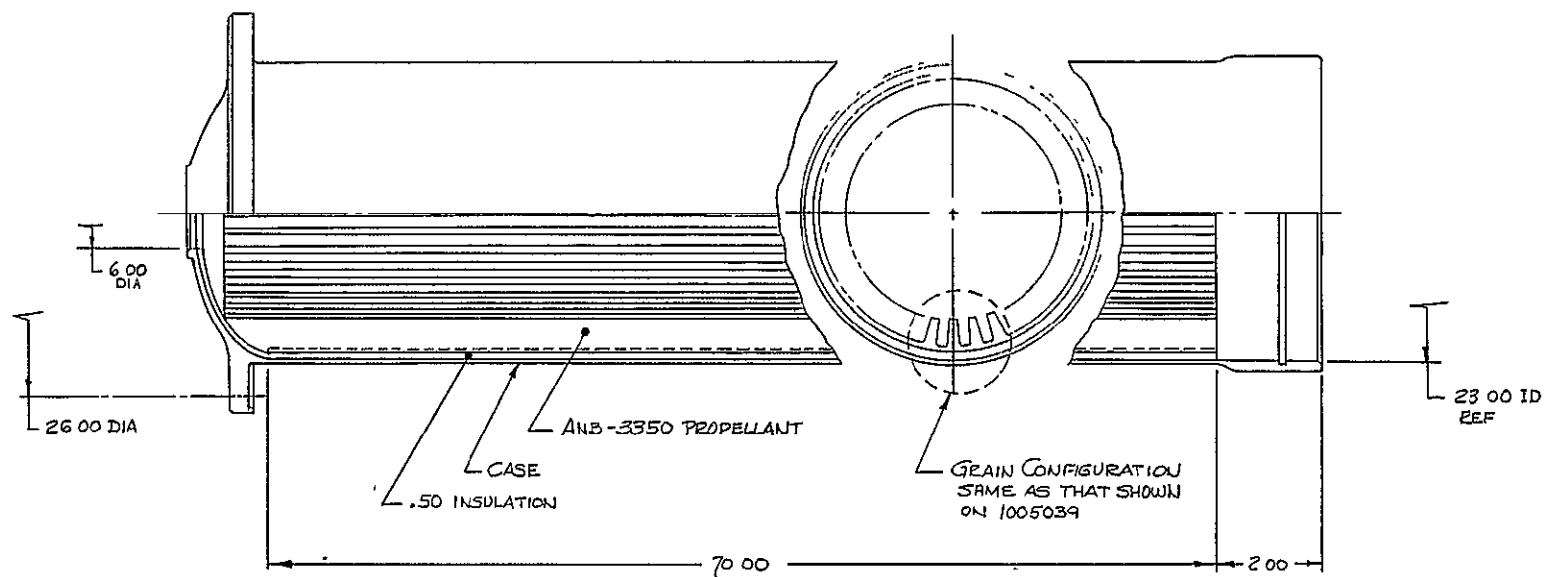


Figure 31

Head-End Igniter for 260-FL Motor

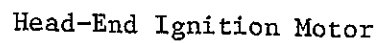
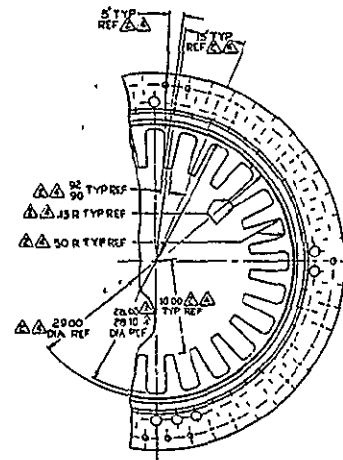
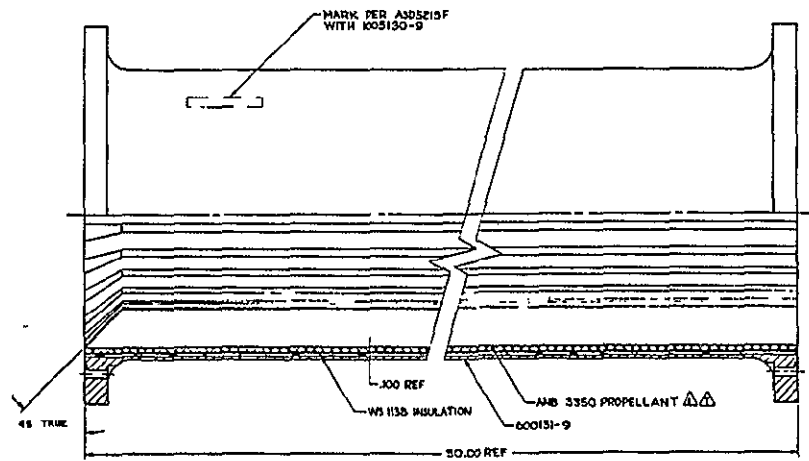


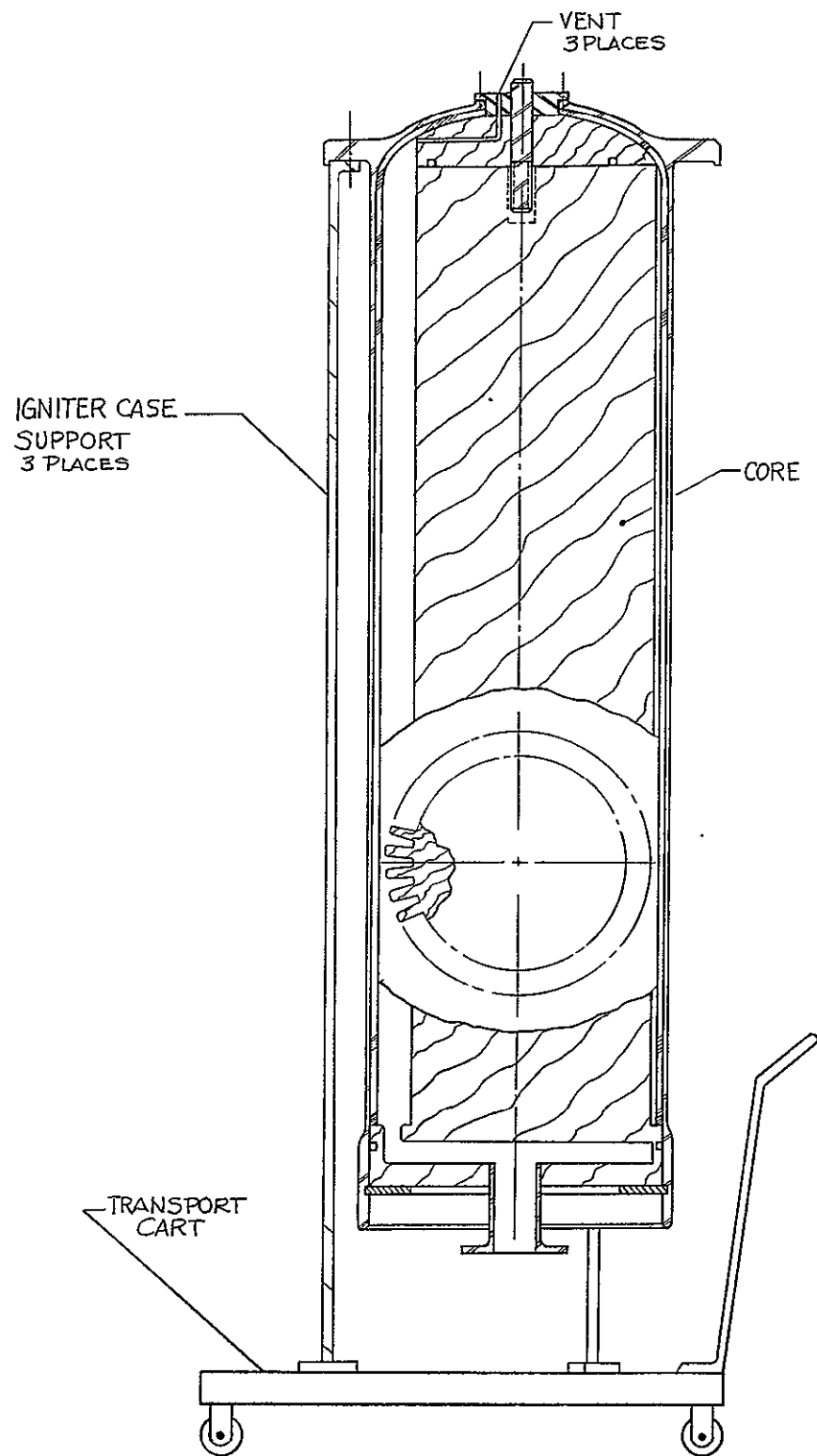
Figure 32

NOTES:

- △ PROCESS PROPELLANT IN ACCORDANCE WITH ASC 3649 OR BY BOTTOM CASTING
IF PROCESSED IN ACCORDANCE WITH ASC 3649, CAST EIGHT PROPELLANT SECTIONS
MEASURING 116 ± 0.15 EACH. UTILIZING 1 VARIOUS PROPELLANT MOLD
- △ DIMENSIONS APPLY AFTER PROPELLANT INSTALLATION
- 3 METHOD OF PRESERVATION PER MIL P 115 METHOD III
- △ GRAIN CONFIGURATION PER 1 1004704
- 3 REMOVED
- 4 REMOVED
- △ MIX AND CURE PROPELLANT IN ACCORDANCE WITH APPROVED ARC PROCEDURE

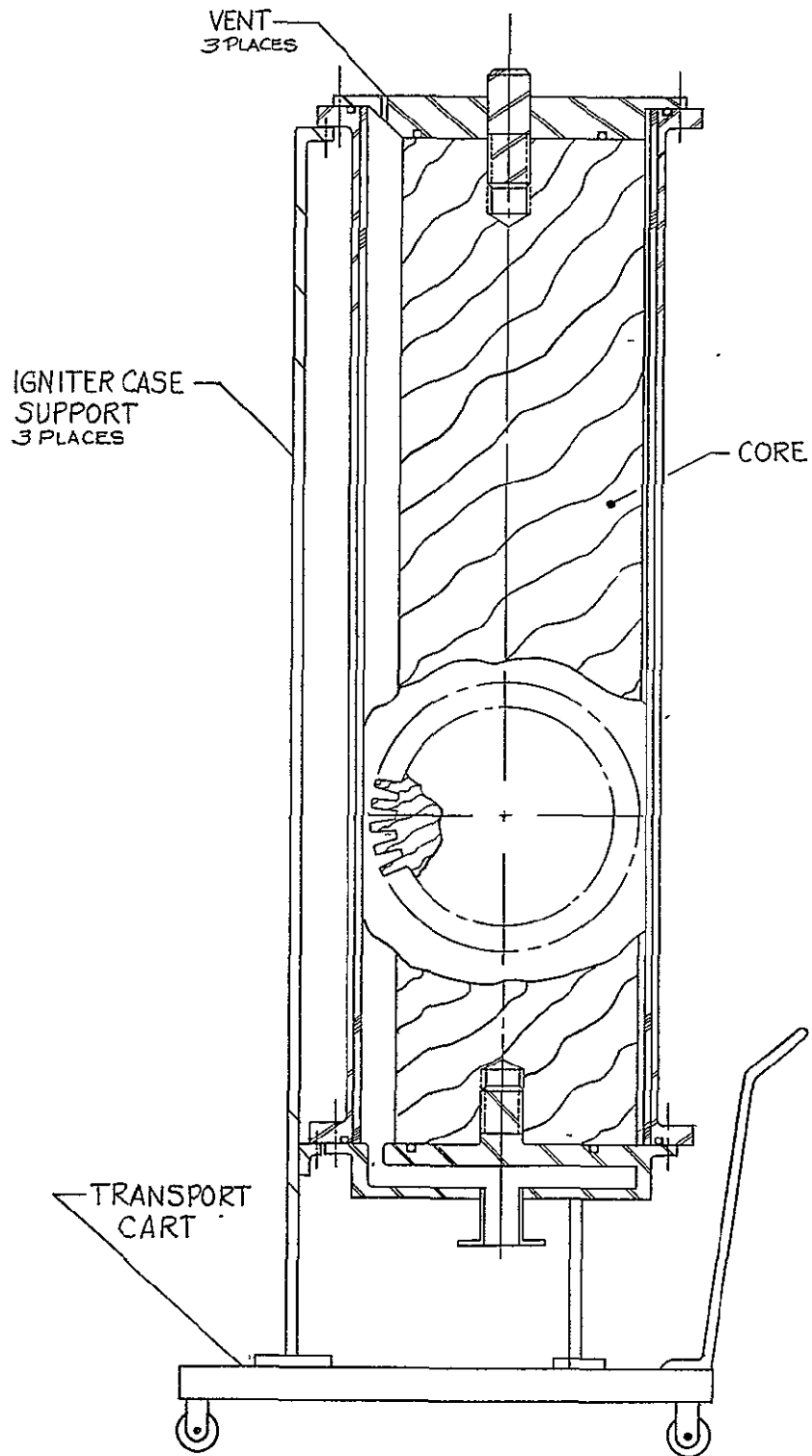


Loaded Ignition Motor Chamber



Bottom Casting Concept, 260-FL Head-End Ignition Motor

Figure 34



Bottom Casting Concept, 260-FL Aft-End Ignition Motor

Figure 35

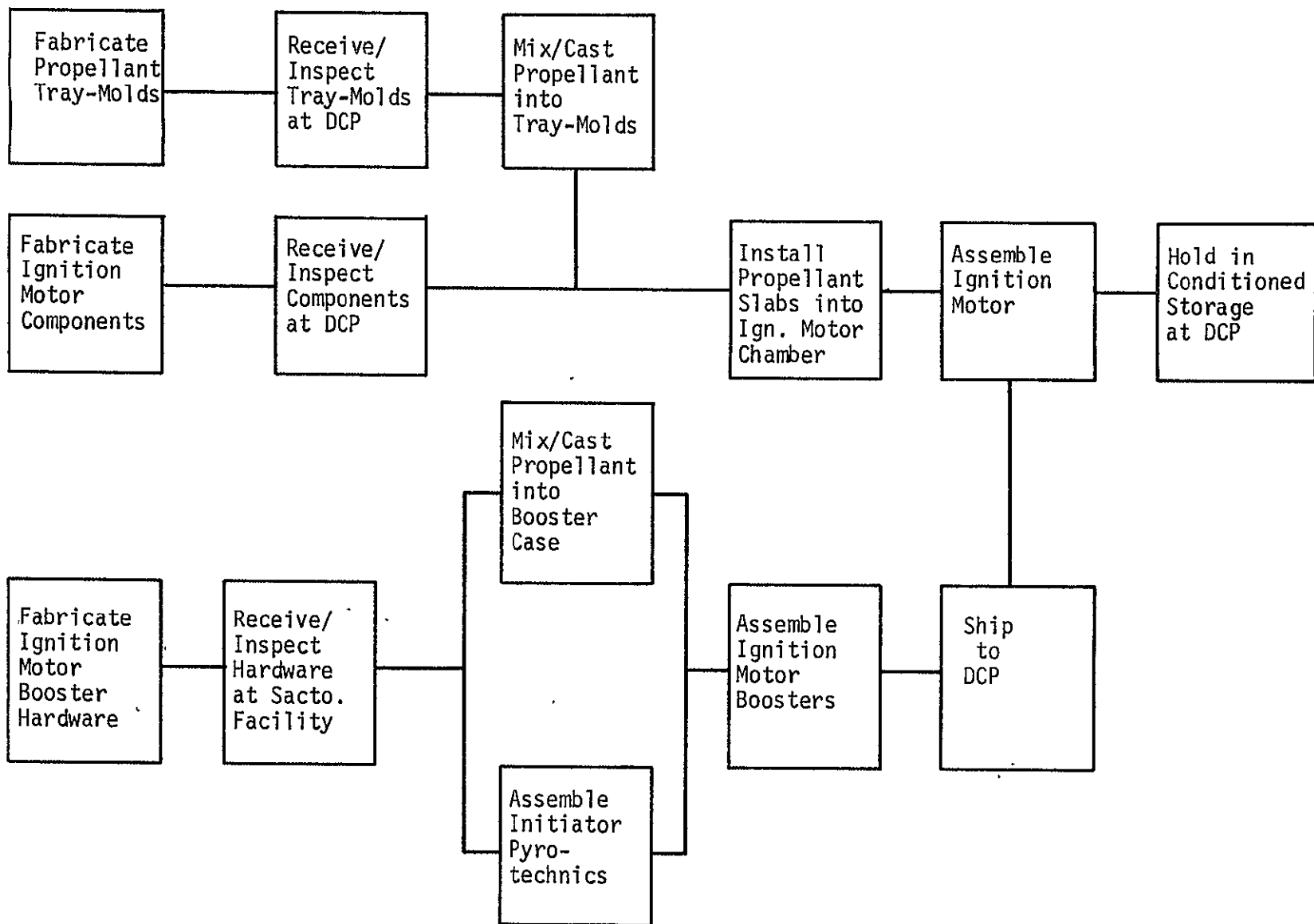
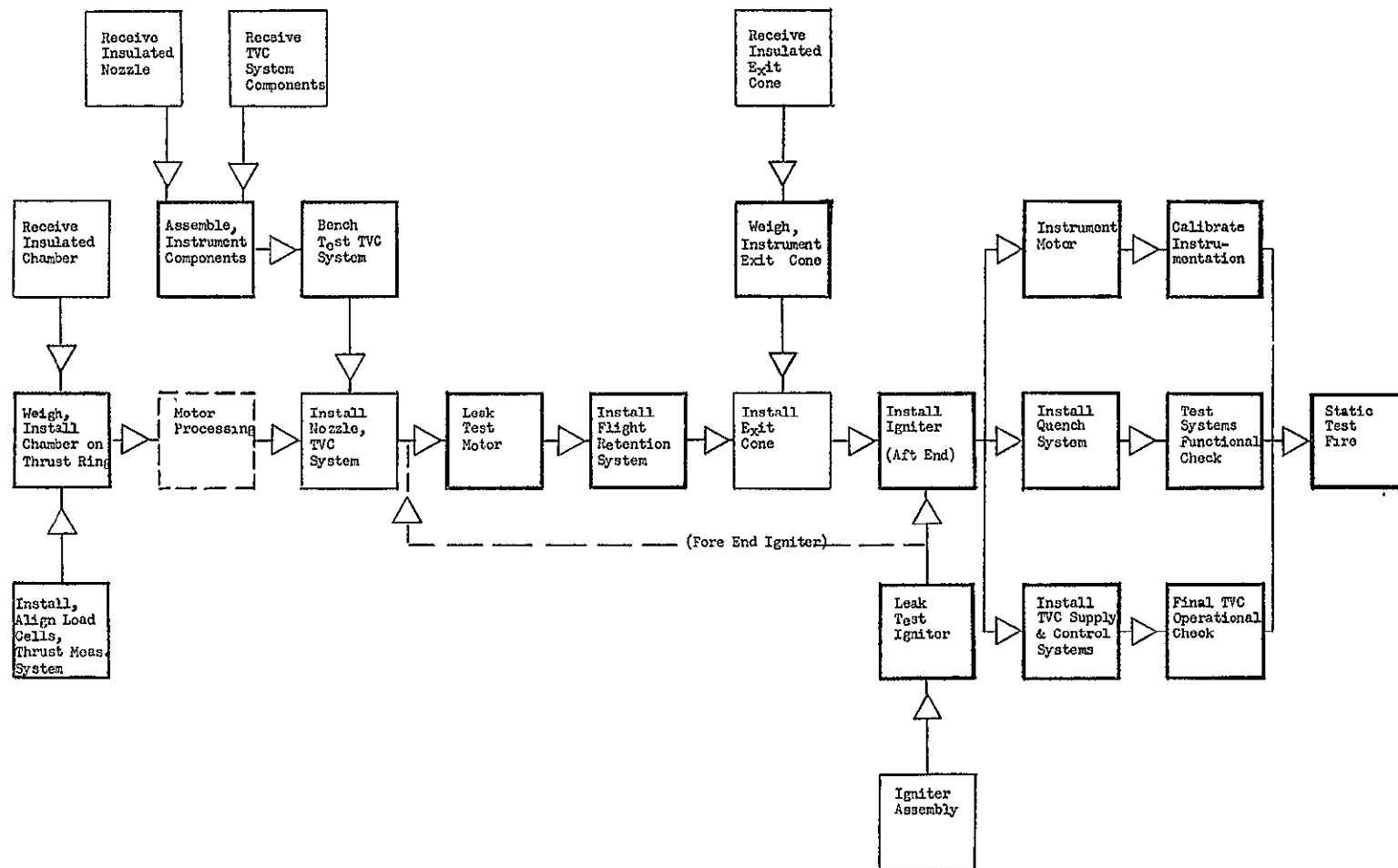
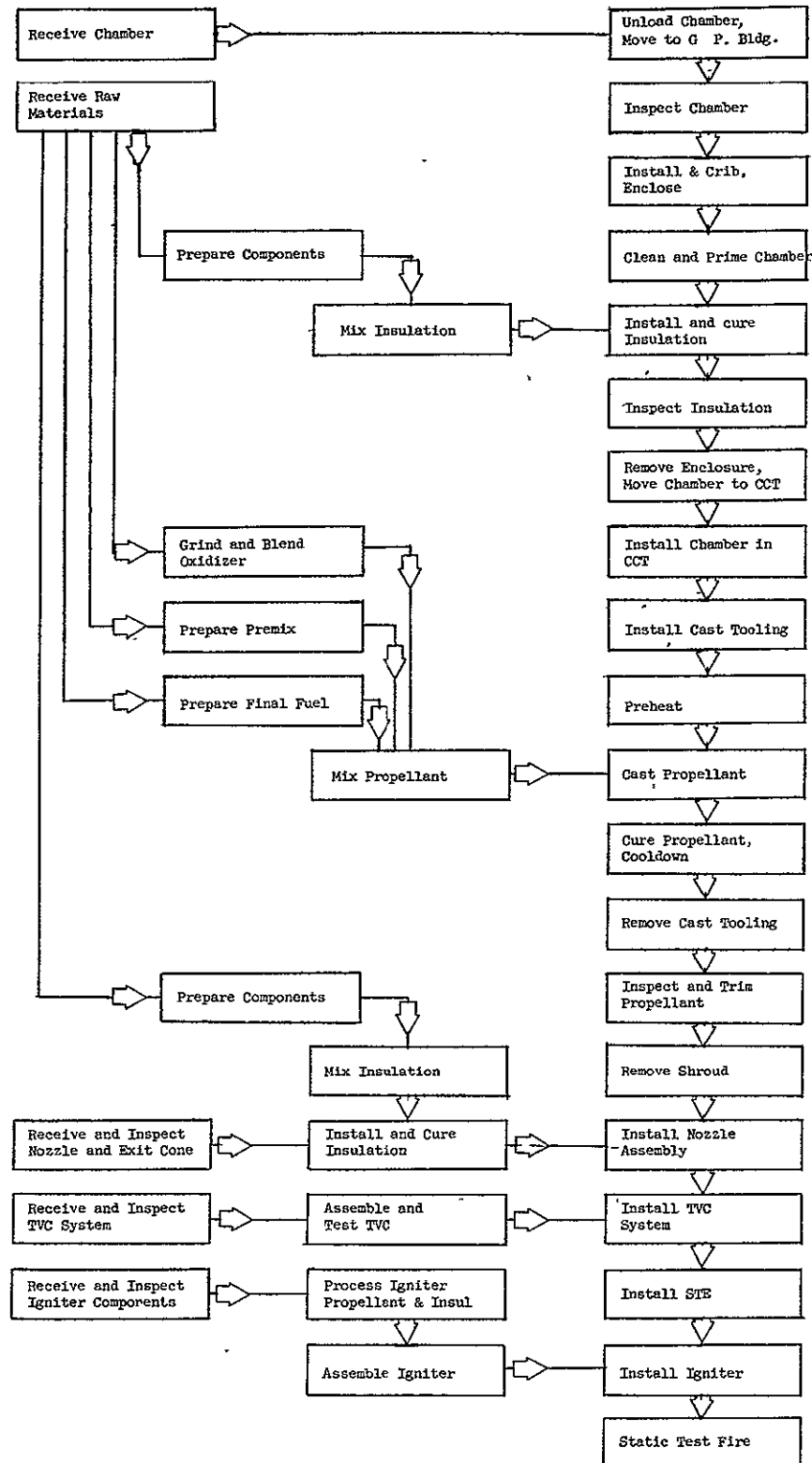


Figure 36

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Figure 37





Motor Processing Flow Chart - Task I

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